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Temperature Profiles Inside and Outside of an Insulated Packaging Container during the FedEx Ground Shipping Environment

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By

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Abstract

In the current pharmaceutical world, cold-chain shipment becomes one of the most important distribution methods. The most widely used cold-chain package is the insulation box that distributed by UPS or FedEx. This study used FedEx Ground Shipping method as the distribution carrier, to measure the temperature inside the insulation box and outside the box, also to estimate the ambient temperature and compare them to see the temperature changing trends; also, to compare the internal temperature and external temperature to see if there is any equilibrium temperature reached during the shipment, and if there is any delay of temperature change. There were no products contained within the container during the shipments but only the sensors. There were two sensors attached on the box per shipment. One sensor was attached outside of the corrugated shipper for the purpose of recording the ambient temperature during the shipment, especially the temperature change on the delivery truck. The other sensor was placed in the insulated container for the purpose of recording the temperature change due to shipment location change. The ambient temperature was extracted from a website that recorded the temperature within hours at each location, this is used only as comparison to see the overall temperature changing trending and if there are any outliers.

INTRODUCTION

The most commonly used package for cold-chain product in the pharmaceutical industry is to use the insulation box for shipping drugs that require strict temperature control.

There are two different storage conditions for cold-chain shipments. One of them is the refrigerator storage statement, which requires the products stored in the refrigerator between 2°C to 8°C (36°F to 46°F). The other one is the freezer storage statement, which requires the products stored in the freezer between -25°C to -10°C (-13°F to 14°F). The most commonly used cold-chain condition is the 2˚C - 8˚C refrigerated temperature, which is critical temperature required for vaccine (Singh, Jaggia, Saha, 2013), and the passive insulated box shipping method is mostly widely used in the pharmaceutical industry. Therefore, temperature profile inside and outside of the insulation box becomes important. This study will help to understand the distribution environment of the ground shipping method, and how the distribution environment temperature affects the temperature inside the insulation box.

PROBLEM DEFINITION

Bio-technology products, for example vaccines, are temperature-sensitive products. The shipping and storage environment is critical for these products, so that when the end-user, including the doctors and nurses in the hospital, drug store or clinic, will receive efficient product to use on the patients (Jay, Jaggia, Saha, 2013). Most of the drug products are produced and shipped throughout the year and distributed to different regions within the United States. The ambient temperature is different geographically in different areas at the same time. How well the insulation box can resist the temperature change on the ambient to reduce the impact to the products in the box is critical. Sudden temperature raised or drop might affect the insulation property of the box.

The purpose of the project is to measure the temperature inside of the insulation box, outside of the box; obtain temperature of the ambient environment. And then make a comparison of each status of the package

for the difference of the temperature for internal and external to find out the pattern of the temperature change during the shipment.

HYPOTHESIS

The temperature in the insulation box will be affected by the ambient and transportation temperature. How does the ambient temperature affect the distribution temperature and how much time the internal temperature would be affected after the external temperature change?

LITERATURE DEFICIENCY

The foam containers are usually made of an expanded polystyrene (EPS) foam. When the pharmaceutical products are distributed in the container, the thickness of the container wall, and how much phase change material should be used to keep the internal temperature within designated range are the biggest concern. There are 2 ways to validate the insulation box can maintain temperature control is to either conduct the thermal insulation test based on ISTA 5B or ASTM D1103, or to take the field test to confirm the container is able to sustain the temperature hazards (Ge, Cheng, Li, 2013). When the products are defined and the required temperature range is identified, it is possible to calculate the required insulating capacity of the container to be used and the amount of phase change material is needed (Matsunaga, Burgess, Lockhart, 2006).

There are three methodss of distributing cold-chain products: carrier-controlled thermal chain, one-way systems, and two-way systems. The carrier-controlled method uses refrigerated trailers to transport the products over long distance, it has the advantage of keeping the distribution temperature under control, but the disadvantage is the high cost. The one-way method had the advantage of rapid package design and validation; the two-way method is very similar to the one-way mode but to reuse the distribution container (Singh, Burgess, Singh, 2007). In the past several decades, the one-way shipment of cold-chain distribution method is critical and open relies on expedited shipping service providers such as FedEx or UPS. To ensure

the product will be delivered within the required temperature, the duration of distribution, size of the package and the ambient temperature that the package is exposed are critical (Jay, Jaggia, Saha, 2013).

There are 3 mechanisms for heat flow: conduction, convection, and radiation. Conduction is the molecule-to-molecule transfer of kinetic energy; convection is the transfer of heat by physically moving heat from one place to another, radiation is the transfer of heat through space by electromagnetic waves. Generally, there are one or mot mechanisms of heat transmission occur, the insulation wall thickness (conduction), number of surfaces (convection) and the number of reflective surface (radiation) determine the insulating ability of the container. The other factor of affecting the thermal conductivity are temperature and moisture. Most thermal conductive materials decrease with temperature (Singh, Burgess, Singh, 2007).

MATERIALS AND EXPERIMENTAL SETUP

This experiment contains two sensors to measure the temperature during the shipment. one of the sensor is placed inside the insulation box for the purpose of measure the internal temperature during the shipment; the other sensor is attached outside of the corrugated shipper to detect the ambient shipment temperature. The external sensor was used to detect the temperature change in the distribution warehouse and delivery truck. Temperature in the warehouse and delivery truck is recorded by www.wunderground.com, which is the website to extract hourly temperature in different area where the delivery truck drove pass.

All the 3 Temperature were channeled into a chart for comparison.

MATERIALS

Material used in the experiment are listed as followed.

External Corrugated shipper – 12” X 10” X 9.75” external, C flute.

Figure 1. External Corrugated Shipper

Insulation box – 11-13/16” X 9-5/16” X 10 external, thickness 2”, EPS.


Figure 2. Insulation Box

Sensor: ThermoWorks ThermoData® Series II, operating range -40°C (-40°F) to 85°C (185°F).

Figure 3. Sensor

Internal corrugated shipper wrapped with form:

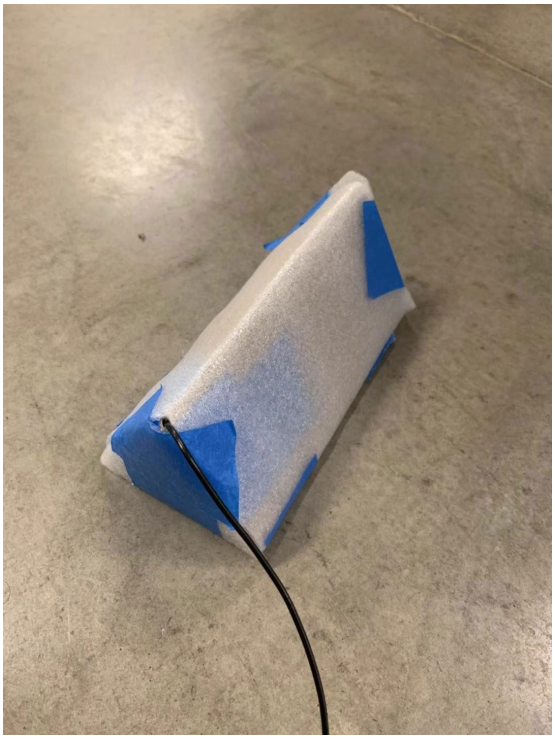

Figure 4. Internal Corrugated Shipper Wrapped with Foam

EXPERIMENTAL SETUP

One of the sensors was securely placed in the internal corrugated shipper inside the insulation box to ensure the stability during distribution from shock and vibration. The other sensor was securely placed in the carton

on the external corrugated shipper, taped to avoid shock and vibration. Both sensors are connected to the data logger placed in the insulation box. The wire connected to the external sensor bypassed the insulation box and the lid.

Figure 5. Package Internal Layout

Figure 6. Sealed Package

In the experiment, the shipment carrier is FedEx and the shipment method used only ground shipping. Long distance driving might cause the ambient temperature to raise higher within FedEx truck, which should also be taken under consideration that might affect the insulation box and the temperature inside.

The data logger was set to start logging the data 30 minutes after started to not only ensure the temperature is stable in the insulation shipper, but also to ensure the data was recorded after the package was received by FedEx.

The packages were shipped from Rochester, NY to Grand Rapids, MI for the first 4 trips. The FedEx tracking number is recorded in table 1.

Table 1. FedEx Tracking Number – Rochester, NY – Grand Rapids, MI

Shipping Order	Shipping Date	Receiving Date	Original	Destination	Tracking Number
1	28-Aug-2020	04-Sep-2020	Rochester, NY	Grand Rapids, MI	396300815372
2	08-Sep-2020	10-Sep-2020	Grand Rapids, MI	Rochester, NY	396616837330

3	07-Sep-2020	10-Sep-2020	Rochester, NY	Grand Rapids, MI	396572611354
4	12-Sep-2020	16-Sep-2020	Grand Rapids, MI	Rochester, NY	396758777341

After that, the rest of the packages were shipped from Rochester, NY to West Palm Beach, FL for 9 trips. The FedEx tracking number is recorded in Table 2.

Table 2. FedEx Tracking Number – Rochester, NY – West Palm Beach, FL

Shipping Order	Shipping Date	Receiving Date	Original	Destination	Tracking Number
5	01-Oct-2020	07-Oct-2020	Rochester, NY	West Palm Beach, FL	397418332681
6	07-Oct-2020	12-Oct-2020	West Palm Beach, FL	Rochester, NY	397603489013
7	09-Oct-2020	12-Oct-2020	Rochester, NY	West Palm Beach, FL	397649324254
8	12-Oct-2020	15-Oct-2020	West Pam Beach, FL	Rochester, NY	397752194059
9	16-Oct-2020	19-Oct-2020	Rochester, NY	West Palm Beach, FL	397888605591
10	27-Oct-2020	30-Oct-2020	Rochester, NY	West Palm Beach, FL	398251903199
11	27-Oct-2020	30-Oct-2020	Rochester, NY	West Palm Beach, FL	398251903188
12	03-Nov-2020	06-Nov-2020	West Palm Beach, FL	Rochester, NY	398532771524

The temperature record stopped when the packages were delivered, due to the reason because the package was left outdoor and is no longer the required information for this study.

RESULTS AND ANALYSIS

The first trip was shipped from Rochester, NY to Grand Rapids, MI in August. The package was shipped at 19:51 on August 28th, Friday. The package was kept in FedEx over the weekend and picked up on Monday, August 31st. The ambient temperature and the recorded temperature showed significant difference because of package was kept in the FedEx storage during the weekend. The package was sent to Syracuse, NY distribution center, then shipped to Grand Rapids, MI by truck. The temperature along the distribution

route was estimated by the time passing the city on I-90. Package was delivered on September 4th, 2020 at 15:48.

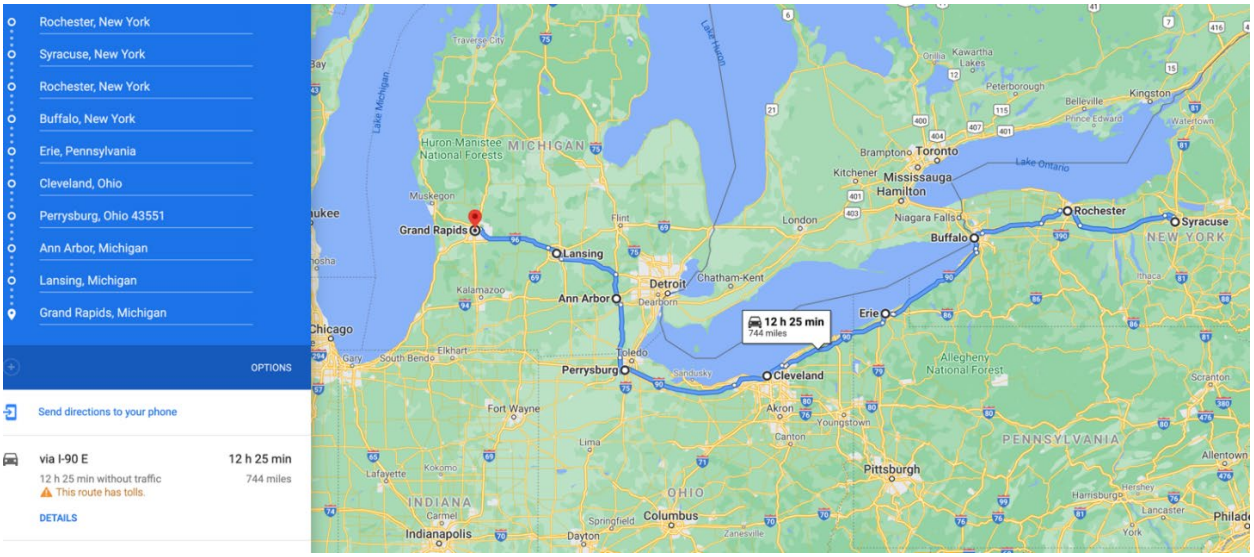

Figure 7. Package 1 Map Route

The graph shown below is the temperature that the sensor tracked. The ambient temperature was extracted from www.wunderground.com weather history based on the location estimated by the traffic time.

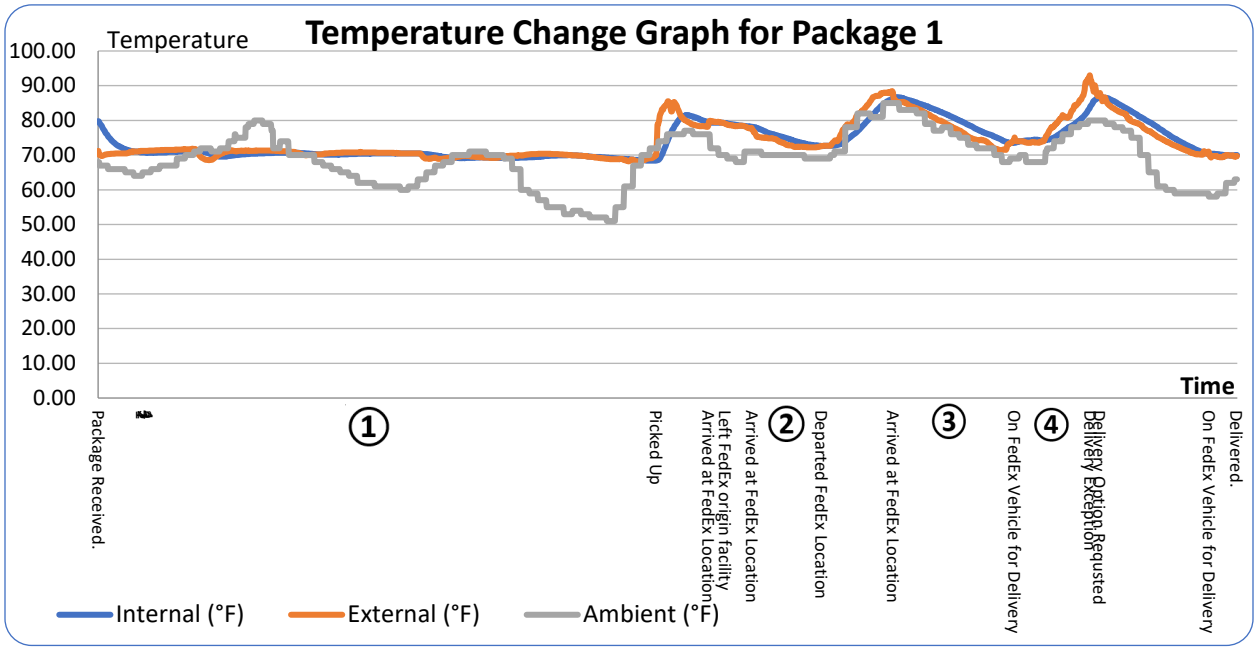

Figure 8. Package 1 Temperature Change Graph

Within interval 1, the package was kept within the warehouse, the internal temperature recorded by sensor 1 and the external temperature recorded by sensor showed 162 data points overlap with each other. When the internal temperature was the same to the external temperature, the temperature reached equilibrium. Unless the temperature was strictly controlled, the external temperature varies, while the internal temperature is more stable with less change. On 28th, August, the first equilibrium was captured at 23:45. 8 minutes later, the equilibrium again was recorded at 23:53. The internal temperature and external temperature maintained the same for the next 40 minutes at 71°F, until the external temperature raised to 71.2°F. The external temperature kept raising for the next 184 minutes to 71.5°F, the internal temperature remained 70.8°F – 70.9°F During the whole time. Since the package was kept in the warehouse, the ambient temperature did not have any impact on the package. The warehouse temperature was kept approximately 70°F throughout the weekend.

Table 3. Package 1 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	79.30	73.40	80.00
Minimum	68.40	68.20	51.00
Difference	10.9	5.2	29.0

After the package was picked up, the external temperature raised to the first peak value at 85.5°F from 13:53 to 14:05. The last equilibrium was met before was at 11:17 at 68.5°F. The temperature raised up to 85.5°F by 156 minutes, while at 14:05 the internal temperature recorded was 73.8°F. The overall temperature increased due to the ambient temperature increase, but the recorded temperature was increased higher than the ambient temperature. The internal temperature reached it's first peak at 16:05 at 81.5°F. This happened 4 hours and 4 minutes after the external temperature's peak, for 4°F less. At 16:05, the external temperature dropped to 79.9°F. The difference of the external and internal temperature was not significant, but indicated that there is an approximately 2 hours lag for the internal temperature to increase temperature if the external temperature fluctuated within 5°F.

Within interval 2, the package arrived the Syracuse distribution center for 8 hours from August 31st 23:53 to September 1st 07:53. The overall trending during this interval, the recorded temperatures decreased

matching the ambient temperature recorded in Syracuse. The internal and external temperature reached to equilibrium at 07:49, which was 4 minutes before the package departure from Syracuse to Perrysburg. The equilibrium temperature was 72.6°F, which while the internal temperature decreased, the external temperature slightly increased. This indicated that the package was already loaded to the truck for the shipment. Even after departed from FedEx location, the internal and external temperature reached equilibrium again from 08:05 to 08:53 at 72.7°F. During this interval, even though both then internal and external temperature decreased matching the ambient temperature decrease trend, the internal temperature experienced a lag for approximately 2 hours after the external temperature decrease.

Table 4. Package 1 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	76.90	75.10	70.00
Minimum	72.60	72.20	69.00
Difference	4.3	2.9	1.00

Within interval 3, the package arrived at Perrysburg distribution, and shipped to the Grand Rapids warehouse. the package arrived at Perrysburg on September 1st at 16:13. The external temperature decreased from 86.1°F to 71.4°F for 12 hours, then the temperature started to increase on September 2nd at 04:59. When the external temperature started to increase, the internal temperature was 74.4°F. In the next 64 minutes, the external temperature increased to 73.5°F, the internal temperature decreased to 73.5°F and reached equilibrium for 8 minutes. The external temperature kept increase but the internal kept 73.5°F for the next 28 minutes before started to increase and match the external temperature increase trend.

Table 5. Package 1 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	86.70	86.10	85.00
Minimum	73.50	71.40	68.00
Difference	13.2	14.7	17.0

Within interval 4, where the package was loaded on to the delivery truck, the internal met equilibrium at 74°F for 24 minutes between 06:45 to 07:09. After that, the internal temperature kept increase slightly while the external temperature decreased to 73.6°F then increased to 91°F. At 09:45, the internal and external

temperature met another equilibrium at 74.3, where the internal temperature remained stable between 74.3°F – 74.5°F, the external temperature experienced slightly larger difference between 73.5°F – 76.8°F. the overall temperature increased matching the increased ambient temperature.

Table 6. Package 1 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	84.20	93.00	80.00
Minimum	73.60	73.50	68.00
Difference	10.6	19.5	12.0

The second trip was shipped from Grand Rapids, MI to Rochester, NY in September. The package was shipped at 16:10 on September 8th, Tuesday. The package was picked up and left the FedEx location and shipped out at 20:29. Package was delivered on September 10th, 2020 at 12:06.

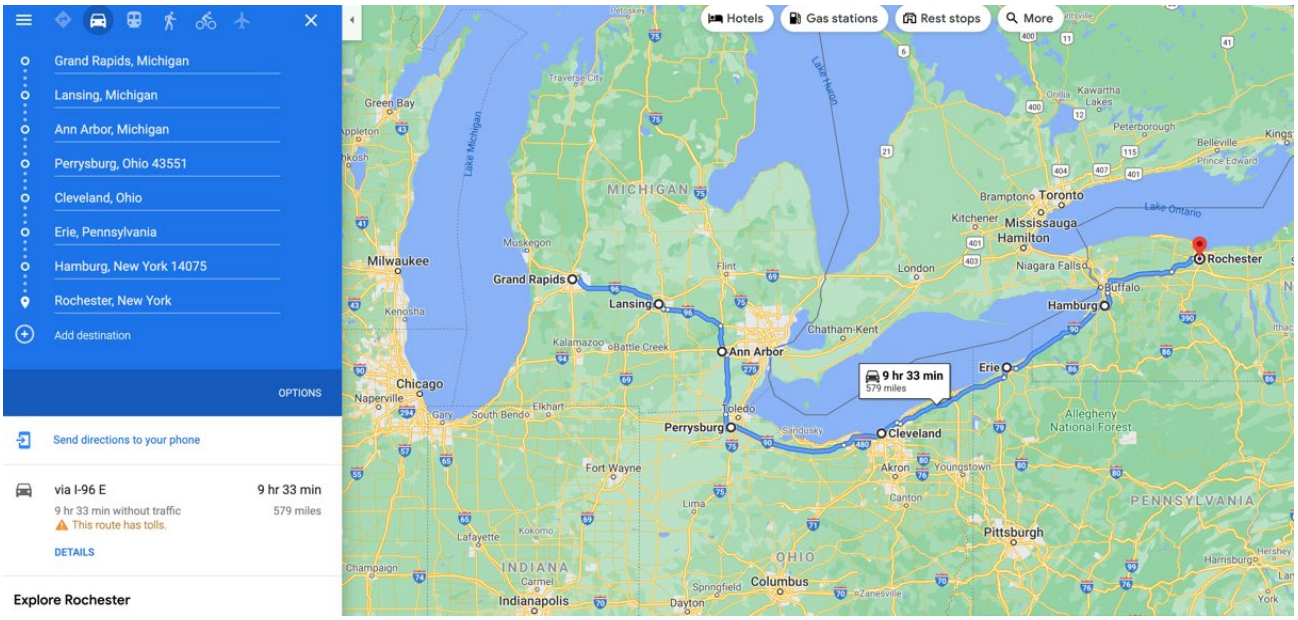

Figure 9. Package 2 Map Route

The graph shown below is the sensor tracked temperature during shipment.

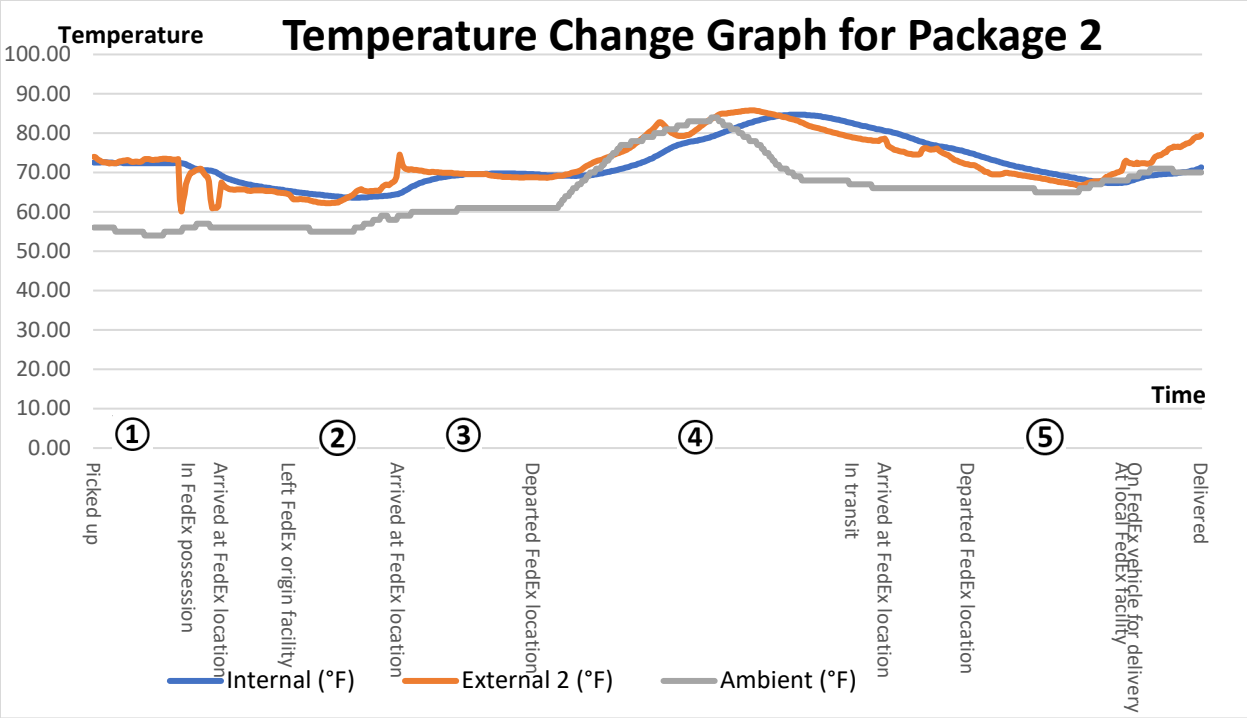

Figure 10. Package 2 Temperature Change Graph

Within interval 1, the package was kept at the FedEx drop off location, which the temperature remained steady for both the internal and external recorded. The external temperature altered between 72.3°F – 73.9°F. The internal temperature was steadier, originally recorded at 72.5°F and decreased to 71.7°F before possession. While the external temperature decreased, there were several equilibrium points where the external temperature and internal temperature are the same. The temperature did not last for long. The first two times happened for 8 minutes from September 8th from 12:28 to 12: 32 at 72.6°F, then from 12:56 to 13:04 at 72.4°F. after the package was possessed, the external temperature experienced a rapid drop to 61°F, which is the first peak shown on the graph. The second peak showed at 62.2°F 2 hours later after the first peak. The internal temperature decreased thoroughly with the overall trend of temperature decrease.

Table 7. Package 2 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	72.60	74.00	56.00
Minimum	71.80	60.10	54.00
Difference	0.8	13.9	2

Within interval 2, the package left the origin facility and sent to the Perrysburg distribution center. The external temperature recorded first decreased from 64.5°F to 62.2°F, then started to increase to 72°F when the package arrived at FedEx location. The internal temperature started at 65.3°F, which was higher than the external temperature. At 22:08 when the external reached the minimum temperature at 62.2°F, the internal temperature was 64.2°F, and kept decrease while the external temperature started to increase at 22:24, finally encountered an equilibrium point at 23:04 at 63.07°F for 8 minutes. After that, the external temperature kept increase and the internal temperature started to increase. The equilibrium temperature was the lowest temperature the internal temperature recorded. While the external temperature increase, the internal temperature did not maintain the same temperature but kept changing followed the external temperature changing trend.

Table 8. Package 2 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	65.40	68.90	59.00
Minimum	63.60	62.20	55.00
Difference	1.8	6.7	4.0

Within interval 3, the external temperature decreased to 68.8°F from 74.6°F, while the internal temperature increased from 64.5°F to 69.6°F. The temperature difference was small due to the reason the package was processed in the Perrysburg distribution center, which is shown on the graph, the recorded temperature slope of this interval is nearly flat. When the package first arrived the location, the external temperature was 72°F on September 9th at 01:06, raised to74.6°F then started to decrease. Meanwhile the internal temperature was 64.5°F when the package arrived the location. Because the external temperature was higher, the internal temperature keep increased. At 04:12, the internal temperature and external temperature first met their equilibrium at 69.6°F. The equilibrium status last for 48 minutes, the internal temperature kept increase to 69.7°F, while the external temperature remained 69.6°F for the next 8 minutes. The internal temperature kept raising to 69.6°F, while the external temperature raised to 68.9°F the highest, before the package departed from FedEx location again.

Table 9. Package 2 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	69.80	74.60	61.00
Minimum	64.50	68.70	58.00
Difference	5.3	5.9	3.0

Within interval 4, the package was shipped from Perrysburg to Hamburg. From the graph, the external temperature recorded highly matched the ambient temperature. Package was shipped out at 07:08 and arrived Hamburg at 21:00. During the time on the truck, the highest temperature recorded by the external sensor was 85.8°F between 16:32 to 16:44. The internal temperature recorded had the highest temperature at 84.7°F from 18:06 to 18:56. The delay of temperature was approximately 2 hours later for the internal temperature increase after the external temperature increase. Even thou the external temperature was unstable, the temperature changed almost every 4 minutes, the internal temperature is more likely to maintain the temperature for longer. The external temperature reached its first peak at 82.8°F between 12:36 to 12:40. This was a sharp increase as this was a 5.3°F increase within 1 hour. The second peak was gentler, one of the reason being the difference was not as huge as the first peak. From the lowest temperature before the peak at 79.3°F, raised to 85.8°F, with 6.5°F increase it took almost 3 hours from 13:40 to 16:32. When the external temperature started to decrease, and the internal temperature kept increase, the equilibrium point at 84.5°F was captured at 17:48. The equilibrium last for 4 minutes then the external temperature continued to decrease and the internal temperature continued to increase. When the internal temperature reached its maximum at 84.7°F, the external temperature was already dropped to 83.7°F. The internal temperature remained at 84.7°F from 18:16 to 18:46, then started to decrease when the external temperature was 82.3°F.

Table 8. Package 2 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	84.70	85.80	84.00
Minimum	69.10	68.60	61.00
Difference	15.6	17.2	23.0

Within interval 5, the package was shipped out from the Buffalo location to West Henrietta facility. The package was shipped out on September 10th at 02:00, with the package internal temperature at 75.1°F,

higher than the external temperature at 72.1°F. Both the internal and external temperature decrease, with the internal temperature decrease rate approximately 2 hours slower than the external temperature, until the externa temperature reached to its minimum temperature at 66.8°F. The external temperature remained at 66.8°F for 8 minutes, then started raising. The equilibrium point appeared at 67.7°F from 07:28 to 07:40. After that, the external temperature continued to increase and the internal temperature continued to decrease.

Table 9. Package 2 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	75.10	72.10	68.00
Minimum	67.30	66.70	65.00
Difference	7.8	5.4	3.0

The third trip was shipped from Rochester, NY to Grand Rapids, MI on Monday, September 7th, 2020. The package was shipped at 16:38. The package left the FedEx location at 20:49, then the package was sent to Syracuse, NY distribution center, then shipped to Grand Rapids, MI by truck.

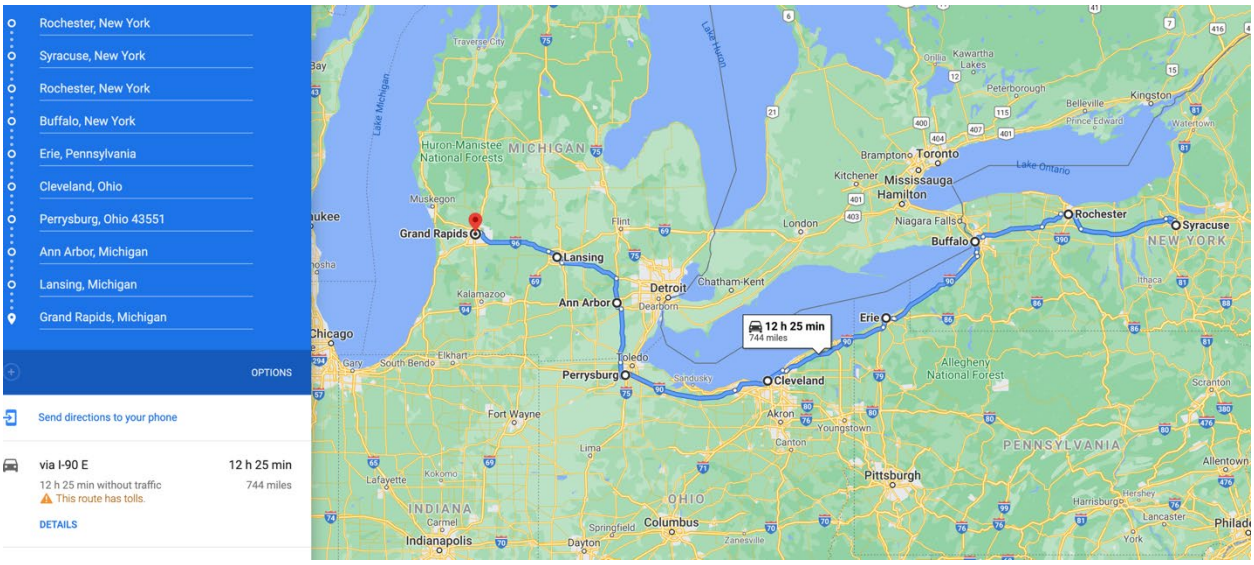

Figure 11. Package 3 Map Route

The graph shown below is the sensor tracked temperature during shipment.

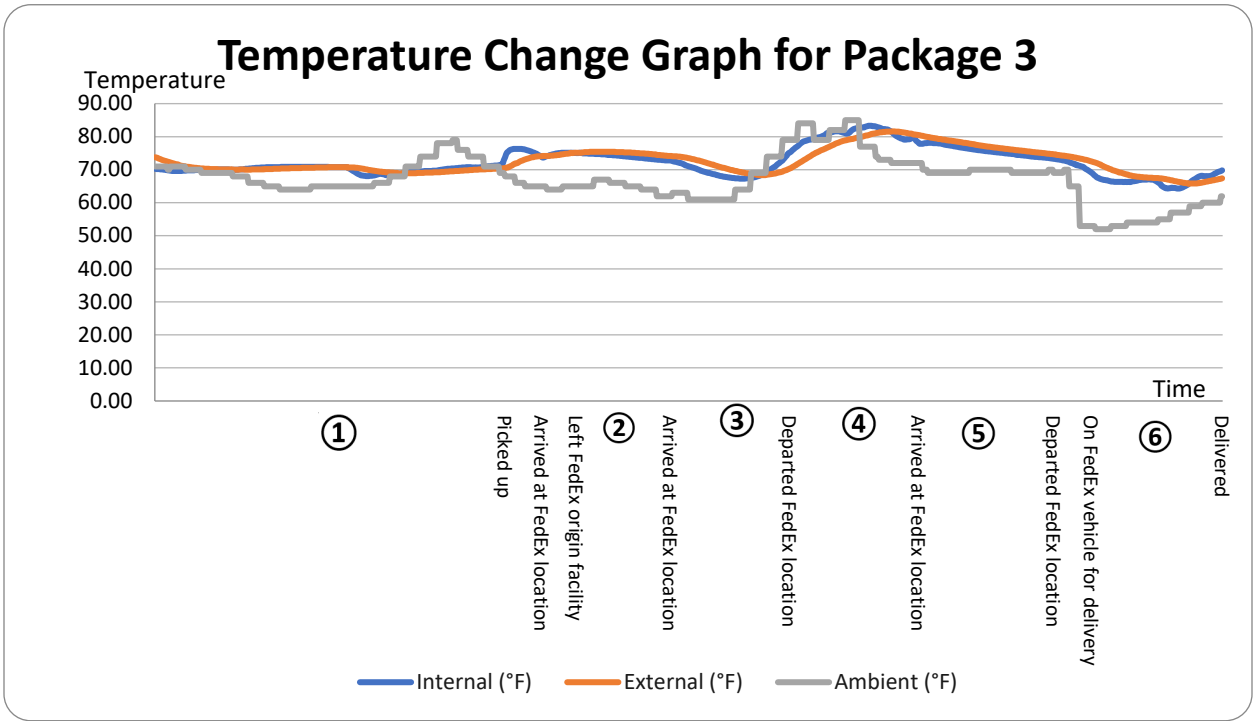

Figure 12. Package 3 Temperature Change Graph

Within interval 1, package was shipped out at 16:38 on September 7th, and picked up at September 8th at 16:14. One third of the trip the package was kept in the warehouse where the shipment was originally generated. The sensors started recording the temperatures at 18:00 on September 7th. In the beginning, the external temperature was 73.8°F and the internal temperature was 70.3°F. Both the internal and external temperature decreased to approximately 70°F, then fluctuated up to 70.1°F. Equilibrium point was reached at 22:00 and lasted until 23:40. Within the 1 hour and forty minutes, there were several times that the external temperature raised up to 70.1°F for the most of 8 minutes, then decreased back to 70°F after. At 23:24, both the internal and external temperature increased back to 70.1°F and lased for 16 minutes. After that, the internal temperature increased more rapidly than the external temperature. the internal raised up to 70.7°F at 02:00 on September 8th and last for 3 hours, decreased to 70.8°F at 05:00. When the internal temperature decreased to 70.8°F, the external temperature raised up to 70.8°F and reached to another equilibrium for the next 1 hour and 8 minutes. In the last 4 minutes of equilibrium, both the internal and external temperature decreased to 70.6°F. After the equilibrium, the internal temperature decreased more rapidly than the external temperature, while the external temperature fluctuated back up to 70.7°F, then

decreased to 68.8°F, the internal temperature decreased to 68.8°F and increased up to 73.8°F when the package was picked up. At the pickup point FedEx recorded, the internal temperature was 73.8°F and the external temperature was 70.5°F.

Table 10. Package 3 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	73.80	73.80	79.00
Minimum	68.10	68.80	64.00
Difference	5.7	5.0	15.0

Within interval 2, the package was shipped out from the West Henrietta facility at 20:49 and delivered to the Syracuse location at 02:47 on September 9th. At 21:00, 11 minutes after the package was shipped out, the internal temperature and external temperature reached an equilibrium at 75.1°F for 12 minutes. After that, the internal temperature slowly decreased to 72.8°F, while the external temperature increased to 75.4°F from 21:40, remained for 96 minutes, then started to decrease to 74.2°F when the package arrived Syracuse.

Table 11. Package 3 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	75.10	75.40	67.00
Minimum	72.80	74.20	62.00
Difference	2.3	1.2	5.0

Within interval 3, the package was kept within the Syracuse distribution center. Both the internal and external temperature decreased from beginning. The internal temperature decreased to 67.3°F at 07:12, lasted for 20 minutes, then started to increase. The external temperature decreased to 68.4°F at 08:24, lasted for 28 minutes, then started to increase. During the time external remained at 68.4°F, the internal temperature increased to 48.4°F at 08:32, which is the only equilibrium point within this interval. The equilibrium lasted for 4 minutes, then the internal temperature continued to increase, while the external temperature remained the same.

Table 12. Package 3 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature

Maximum	75.20	74.20	79.00
Minimum	67.30	68.40	61.00
Difference	7.9	5.8	18

Within interval 4, the package was shipped out from the Syracuse facility and shipped to the Perrysburg location. Within this interval, there was only 1 equilibrium temperature recorded for 4 minutes. the internal temperature was unexpected higher than the external temperature. When the package departed from FedEx location at 10:24, the internal temperature was 75.2°F and the external temperature was 70.4°F. After package left the facility, both the internal temperature and external temperature increases, which matched the overall ambient temperature changing trend estimated. The highest temperature recorded internally was 83.3°F, from 15:24 to 15:36, then the temperature started to decrease. The external temperature sensor recorded the highest temperature at 81.6°F, between 17:00 to 17:04. When the internal temperature decreased to 81.5°F, while the external temperature remained the same from 16:32 to 15:52, the internal temperature and external temperature reached the equilibrium at 81.5°F for 4 minutes. After that, the external temperature increased to 81.6°F for 12 minutes, then dropped back to 81.5°F while the internal temperature decreased to 80.4°F.

Table 13. Package 3 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	83.30	81.60	85.00
Minimum	75.20	70.40	72.00
Difference	8.1	11.2	13

Within interval 5, the package was processed in the Perrysburg facility. There was no equilibrium temperature recorded in this interval. Both the internal and external temperature decreased from the beginning, when the package arrived the facility at 18:36 until the package departed from the location. The internal temperature decreased from 78.1°F to 73.3°F, and the external temperature decreased from 80.5°F to 74.6. The external temperature were higher than the internal temperature during the entire interval.

Table 14. Package 3 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	78.10	80.50	72.00
Minimum	73.30	74.60	69.00
Difference	4.8	5.9	3.0

Within interval 6, the package was on the delivery truck and out for delivery. Initially, the internal temperature was 69.1°F, and the external temperature was 72.5°F. the internal temperature reached to the lowest temperature at 64.3°F at 10:28, and the external temperature reached the lowest temperature at 66°Fat 11:28. In this trip, the temperature difference of the internal temperature was larger than the external temperature difference.

Table 15. Package 3 Interval 6 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	69.80	72.50	62.00
Minimum	64.30	65.70	52.00
Difference	5.5	6.8	10.0

The fourth trip was shipped from Grand Rapids, MI to Rochester, NY on September 12th, Saturday. The package was kept in FedEx location and picked up on Monday, September 14th, at 13:50. This package was shipped to the Syracuse, NY distribution, then sent to Rochester, NY for delivery.

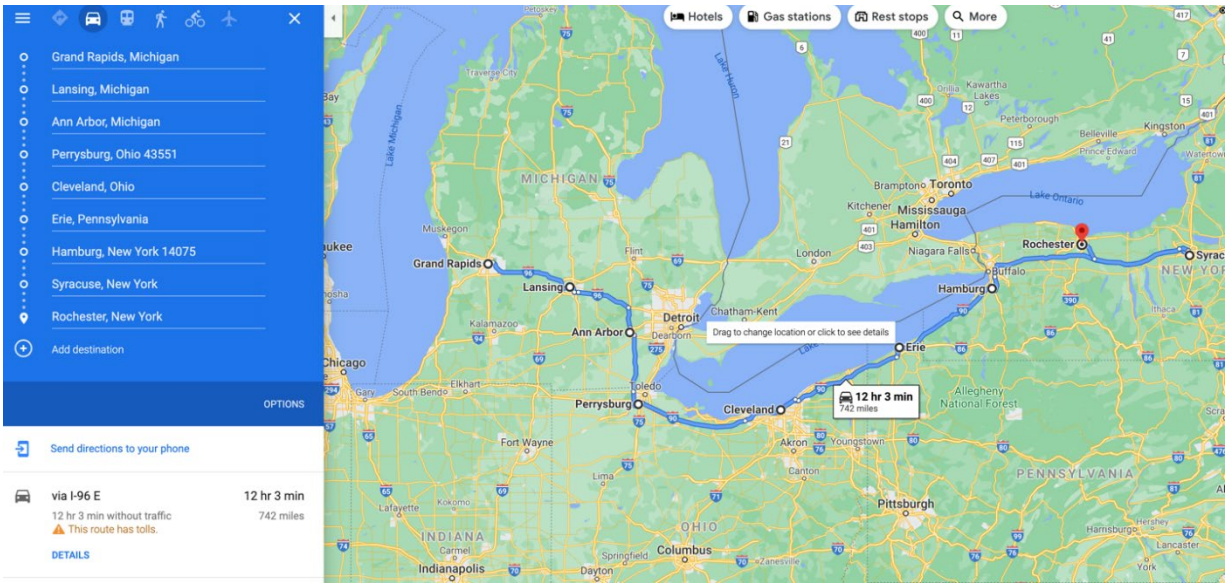

Figure 13. Package 4 Map Route

The graph shown below is the sensor tracked temperature during shipment.

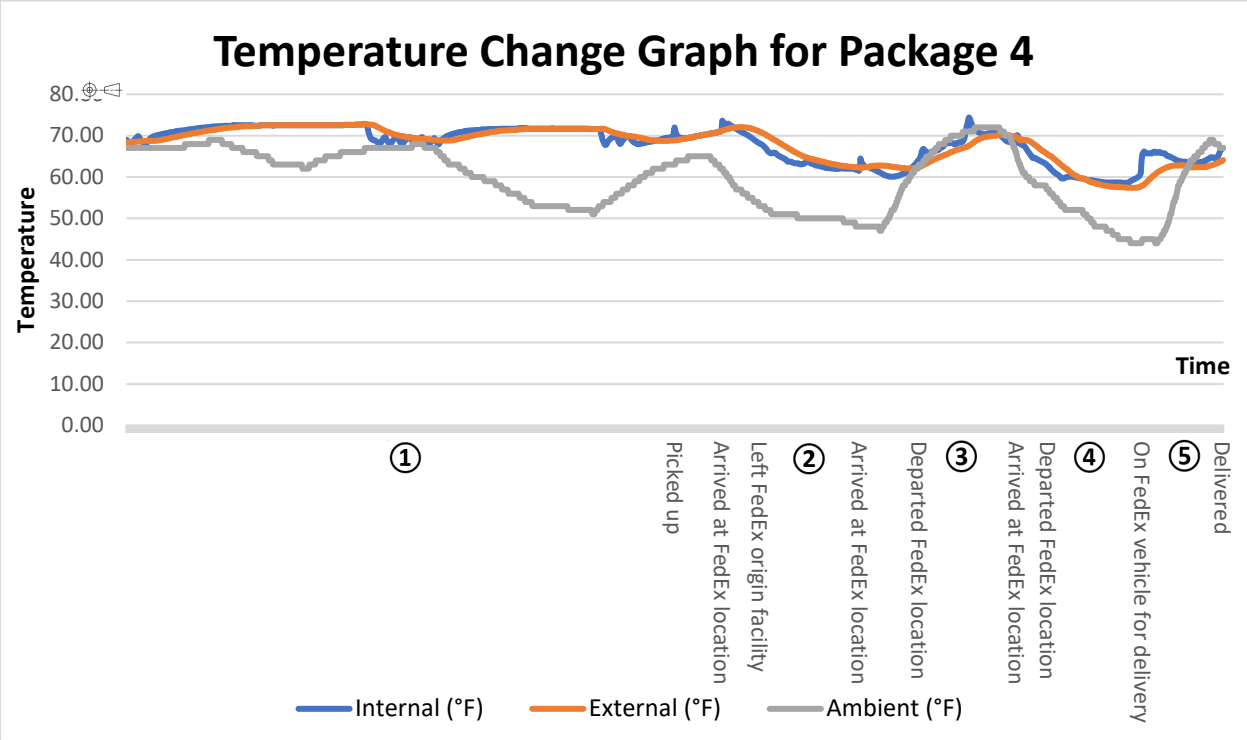

Figure 14. Package 4 Temperature Change Graph

Within interval 1, package was kept in the original FedEx facility, there were not significant temperature difference for the internal and external temperature recorded. There were several equilibrium points recorded. The sensor started recording the temperature at 16:03 on September 12th. The initial internal

temperature was 69°F and the external temperature was 68.4°F. The internal temperature fluctuated slightly between 68°F and 69°F, then slowly increased to 71.8°F. The external temperature was more stable, slowly increased from 68.4°F to 72.8°F. The first equilibrium started on September 13th at 02:39 at 72.4°F and lasted for 28 minutes. After that, both the internal and external temperature raised up to 72.5°F at 03:15 and last 6 hours and 52 minutes, then raised to 72. 6°F from 10:15, lasted 52 minutes. At 11:15, both internal and external raised up to 72.7°F, last 28 minutes, then 72.8°F from 11:51 to 12:03. Temperature decreased after the equilibrium points until September 14th, at 1:31, both the internal and external temperature reached to 71.7°F until 6:31 the internal temperature decreased to 71.6°F. After that, the external temperature decreased to 71.6°F, reached another equilibrium for the next 40 minutes. By the time package was picked up at 13:51, the internal temperature was 71.2°F and the external temperature was 68.9.

Table 16. Package 4 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	72.8	72.8	69
Minimum	67.6	68.4	51
Difference	5.2	4.4	18

Within interval 2, package was shipped out from Grand Rapids at 20:55 and arrived the Perrysburg distribution location at 5:14 on September 15th. There was no equilibrium temperature in this interval. the internal temperature decreased from 68.1°F to 61.9°F, while the external temperature decreased from 70.9°F to 62.3°F. The external temperatures were always higher than the internal temperature, while the ambient temperature showed approximately 10°F lower than the recorded temperature, the decreasing trend still match the slope.

Table 17. Package 4 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	68.1	70.9	53
Minimum	61.5	62.3	48
Difference	6.6	8.6	5

Within interval 3, package was shipped out from Perrysburg at 10:14 and arrived Syracuse facility at 18:20. Initially when the package was shipped out, the internal temperature was 64.4°F and the external temperature was 62.5°F. Both internal and external temperature increased to a peak, then dropped down slowly. The highest temperature the internal sensor recorded was 74.4°F at 14:23; the highest temperature recorded by the external temperature was 70.2°F at 17:07. The difference between the internal and external temperature were not significant. When the internal temperature decreased, and the external temperature remained stable, the equilibrium point was reached at 70.1°F from 16:51 to 16:59. After that, the internal temperature continued to decrease, and the external temperature increased to 70.2°F.

Table 18. Package 4 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	74.4	70.2	72
Minimum	64.4	62.5	63
Difference	10	7.7	9

Within interval 4, package was shipped out from Syracuse and shipped to West Henrietta. The internal temperature started at 62.6°F when the package was originally shipped out. The external temperature was 65.3°F. As the package left the facility, the temperature decreased for both internal and external. The temperature difference of the external temperature was bigger than the internal, therefore there were several equilibrium points recorded at 59.8°F, 59.6°F, 59.4°F and 59.2°F. The temperatures were not stable and changed every 4-8 minutes. The internal temperature reached its minimum temperature at 58.6°F at 03:07. While the external temperature reached its minimum temperature at 57.4°F at 3:31. When the package was delivered and out for delivery, the temperature was 65.6°F internally and 58°F externally.

Table 19. Package 4 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	65.6	65.3	57
Minimum	58.5	57.4	44
Difference	7.1	7.9	13

Within interval 5, the package was out for delivery. Fifty-six minutes after the package left the facility, at 5:59, the internal temperature reached its maximum temperature at 65.9°F and last for 4 minutes. After that, the temperature decreased to 63.5°F at 9:23 and last for 16 minutes before raised back up. The external temperature first increased to 62.9°F at 8:07, then decreased to 62.3°F at 9:19, and raised back up to 64.1°F when the package was delivered. There was no equilibrium within this interval.

Table 20. Package 4 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	67	64.1	69
Minimum	63.1	58	44
Difference	3.9	6.1	25

The fifth package was shipped from Rochester, NY to West Palm Beach, FL on October 1st, 2020. Package was dropped off at FedEx location at 19:58 and picked up at 18:44 on October 2nd, 2020. The package was shipped to Syracuse, NY distribution facility then shipped to Belle Isle, FL distribution facility. The Belle Isle, FL facility was over capacity during that time, the package was hold at the facility for 1 day before it was sorted out and shipped to West Palm Beach, FL.

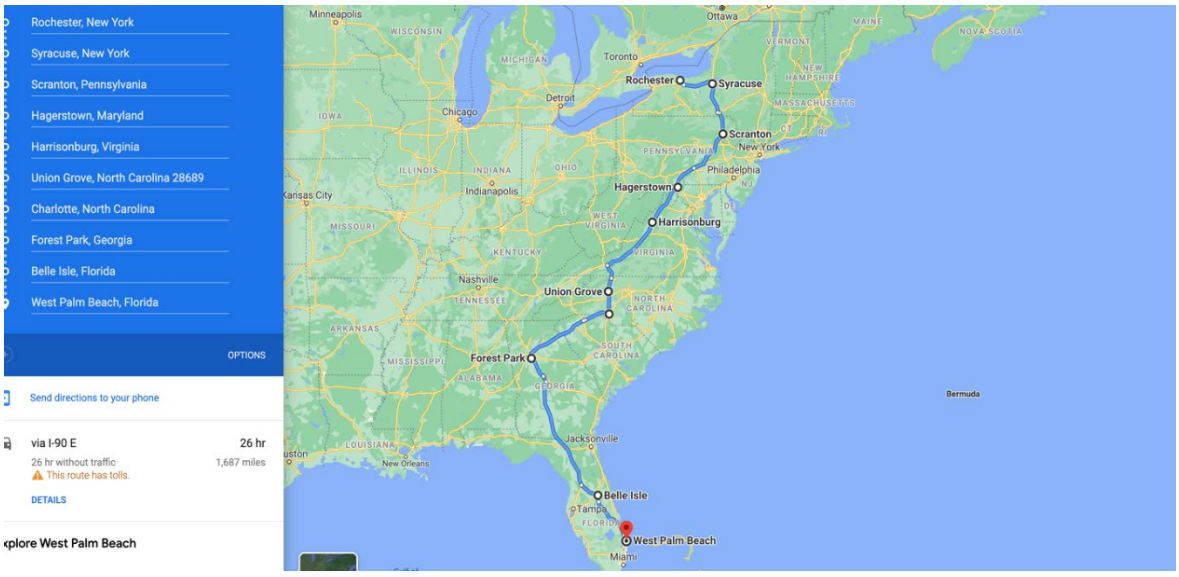

Figure 15. Package 5 Map Route

The graph shown below is the sensor tracked temperature during shipment.

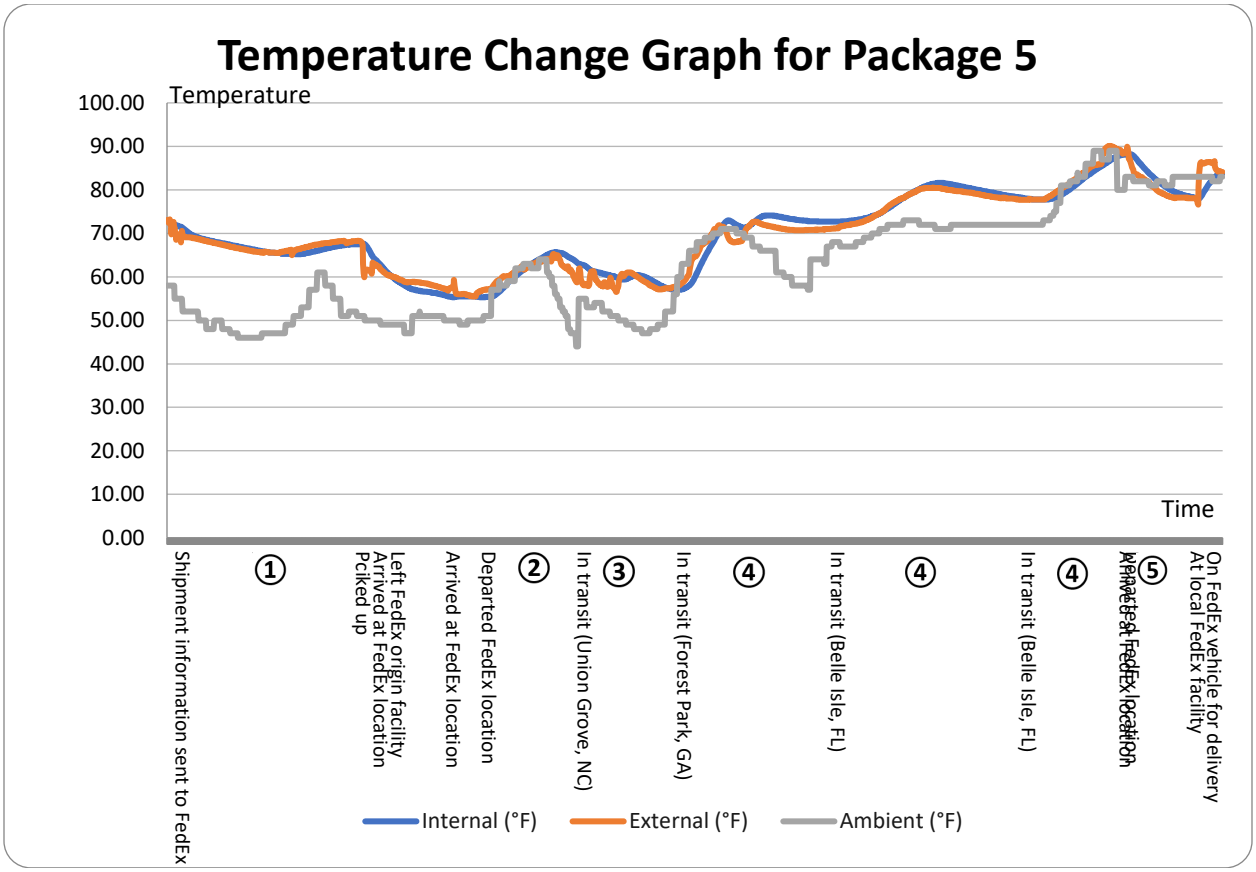

Figure 16. Package 5 Temperature Change Graph

Within interval 1, the package was dropped at FedEx facility with the internal temperature of 71.2°F and external temperature of 69.5°F. The external temperature decreased to the minimum temperature within this interval at 65.5°F at 06:07 on October 2nd. The internal temperature decreased slower than the external temperature but reached the equilibrium first at 65.8°F when the external temperature raised back up to 65.8°F at 06:15. The equilibrium last 8 minutes, then dropped to 65.7°F at 06:31, lasted for 12 minutes. After that, both the internal and external temperature decreased to 65.5°F from 06:51, last 80 minutes. After the equilibrium, the internal temperature continued to decrease to its minimum temperature at 65.2°F at 10:07. When the package was picked up, the internal temperature raised up to 67.6°F, and the external temperature raised up to 67.8°F. At the moment package was picked up, the internal temperature remained 67.6°F but the external temperature rapidly dropped to 62.9, and continued to decrease to 60.8°F, then started to raise back up again.

Table 21. Package 5 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	71.2	69.5	61
Minimum	65.2	62.9	46
Difference	6	6.6	15

Within interval 2, the package departed from the Syracuse facility on October 3rd. When the package left the facility, the internal temperature was 55.4°F and the external temperature was 57.2°F. Initially the internal temperature was lower than the external temperature, but the internal temperature increased more rapidly than the external temperature and reached the first equilibrium point at 61.7°F at 14:59 and last 8 minutes. Eight minutes later, both the internal and external temperature reached another equilibrium at 62°F, then increased and remain equilibrium for the next 8 minutes, to 61.2°F then 62.3°F. At 15:39, another equilibrium point was reached at 62.6°F and last for 8 minutes, then raised up to 62.7°F, then 62.8°F. Four minutes later, the fourth equilibrium point was reached at 63.1°F and lasted for 8 minutes. After that, the internal temperature rapidly increased to 65.7°F, while the highest temperature the external temperature reached was 65°F, 8 minutes after the internal temperature reached to the peak. The temperature decreased slowly for both internal and external until the package was delivered to the transit in Union Grove, NC.

Table 22. Package 5 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	65.7	65.3	64
Minimum	55.4	57.2	44
Difference	10.3	8.1	20

The package arrived Union Grove at 22:43 with the internal temperature of 62.5°F and external temperature of 58.1°F. Within interval 4, the first equilibrium point was met at 23:43 at 61.2°F. The equilibrium last for 4 minutes, then the external temperature started to decrease faster than the internal temperature. At 2:39 on October 4th, external temperature reached its first minimum temperature at 56.5°F, while the internal temperature was 59.9°F. The external temperature raised rapidly to the second peak within this interval at 61°F at 4:03, then started to decrease. The internal temperature raised up to 60.4°F, then started to decrease

and reached the second equilibrium point at 8:51 at 57.4°F. The equilibrium last 16 minutes, then decreased to 57.3°F and last for 12 minutes. The package arrived at the Forest Park transit in GA at 11:19.

Table 23. Package 5 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	62.5	61.3	63
Minimum	57	56.5	47
Difference	5.5	4.8	16

Within interval 4, there was a shipment delay occurred. The package left the Forest Park facility and sent to the Belle Isle facility on October 4th. The Belle Isle facility was over capacity over the weekend, the package was kept in the facility and proceed on the next day. When the package arrived the Forest Park facility, the internal temperature was 57.4°F and the external temperature was 59.2°F. Both the internal and external temperature increased after the package arrived. The external temperature increased more rapidly, reached to 71.9°F at 15:39, when the internal temperature was 70.5°F. The external temperature then started to decrease, while the internal temperature continued to increase, reached the first equilibrium point at 71.5°F at 15:59. The equilibrium point only lasted for 4 minutes, then the internal temperature continued to increase, and the external temperature remained the same for the next 12 minutes, then started to decrease again. The internal temperature continued to increase to 73°F at 16:47, remained for 4 minutes, then started to decrease. The external temperature decreased to 68.1°F at 18:11, remained 4 minutes then started to increase. The second equilibrium point was met at 19:15 at 71.4°F. The equilibrium point only last for 4 minutes, then both the internal and external temperature continued to increase, and reached another equilibrium point at 19:59 at 72.6°F. Both internal and external temperature remained 72.6°F for 8 minutes, then both increased to 72.7°F and remained for 4 minutes. After that, the internal temperature continued to increase up to 74.1°F, and the external temperature started to decrease. When the package arrived the Belle Isle facility on October 5th, the internal temperature was 72.7°F and the external temperature was 71.2°F and the graph showed that the temperature did not fluctuated significantly. Both the internal and external temperature increased after the package's arrival to Belle Isle facility. The equilibrium point was met at

11:15 at the 74.1°F, and last for 12 minutes. There was slightly fluctuation after the equilibrium, both the internal and external temperature increased slightly and met again at 74.3°F, then 74.4°F, 74.5°F, 74.8°F, 75.1°F, 75.3°F and 75.5°F within the next hour. The temperature continued to increase to 78°F, and met another equilibrium at 14:43. As both temperature continued to increase, the equilibrium temperatures were met at 78.1°F, 78.3°F, 78.5°F, 78.6°F, 78.8°F, 79°F 79.2°F, and 79.4°F when both the internal and external temperature raised simultaneously.

The overall temperature changing trend was increasing within interval 4. The maximum temperature the external temperature reached was at 80.5°F at 18:31. The maximum temperature that the internal temperature reached was 81.6°F at 19:11, and remain the same for the next 48 minutes then started to decrease. From the graph, when the temperature increase, the external temperature tends to be higher than the internal temperature. When the external temperature reached the maximum and decrease, the internal temperature would continue to increase, even reach the temperature that was higher than the external temperature, then slowly decrease. Until October 6th, both the internal and external temperature decreased to 77.8°F and last for 100 from 7:07 to 8:78. After that, the internal temperature remained the same for the next 28 minutes, when the external temperature raised up to 78.4°F. The maximum temperature recorded by external sensor was at 16:55 at 90.1°F, when the internal temperature was 86.7°F.

Table 24. Package 5 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	88.2	90.1	89
Minimum	57.4	59.2	57
Difference	30.8	30.9	32

Within interval 5, package left the Orlando facility and shipped to the West Palm Beach facility. When the package departed, the internal temperature was 88°F and the external temperature was 84.9°F. Both the internal and external temperature decreased within this interval. The external temperature reached 78.1°F from October 7th at 2:51, remain the same until 3:55, while the internal temperature reached to 78.1°F for the equilibrium from 3:43 to 4:19. The equilibrium status last form 3:43 to 3:55.

Table 25. Package 5 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	88	84.9	83
Minimum	78.1	76.6	81
Difference	9.9	8.3	2

The sixth package was shipped from West Palm Beach, FL to Rochester, NY on October 7th, 2020. The package was dropped off at the FedEx location at 16:15, and picked up at 18:48, left West Palm Beach, FL facility at 20:00. The package was shipped to Syracuse, NY distribution on Sunday, October 11th, 2020 and delivered on October 12th, 2020 at 11:10.

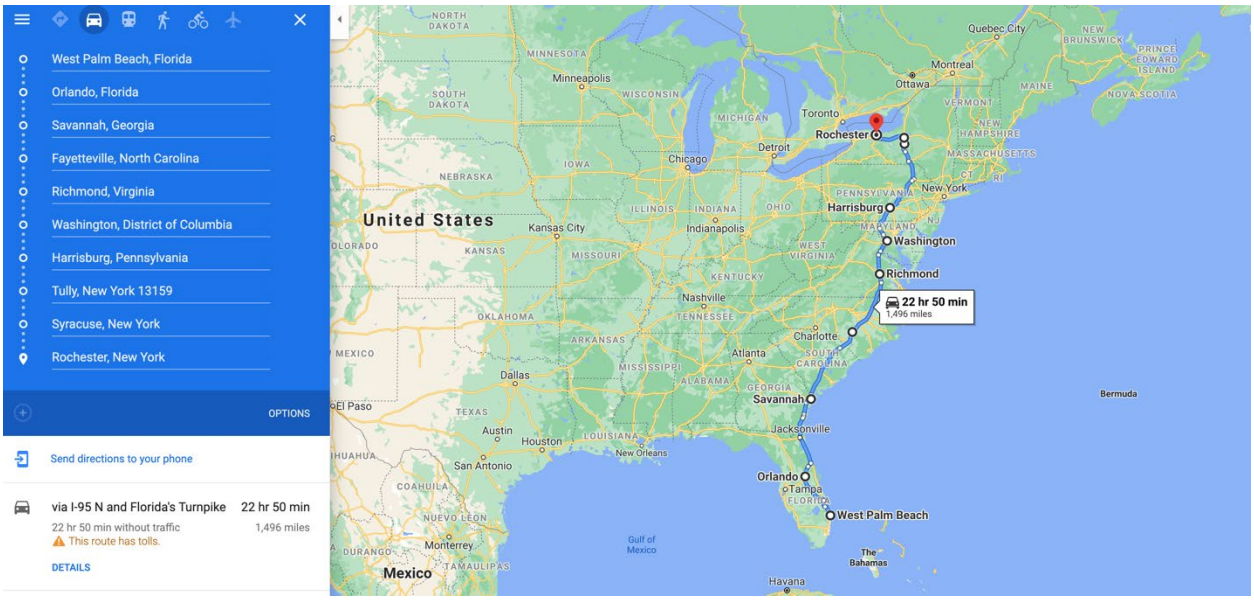

Figure 17. Package 6 Map Route

The graph shown below is the sensor tracked temperature during shipment.

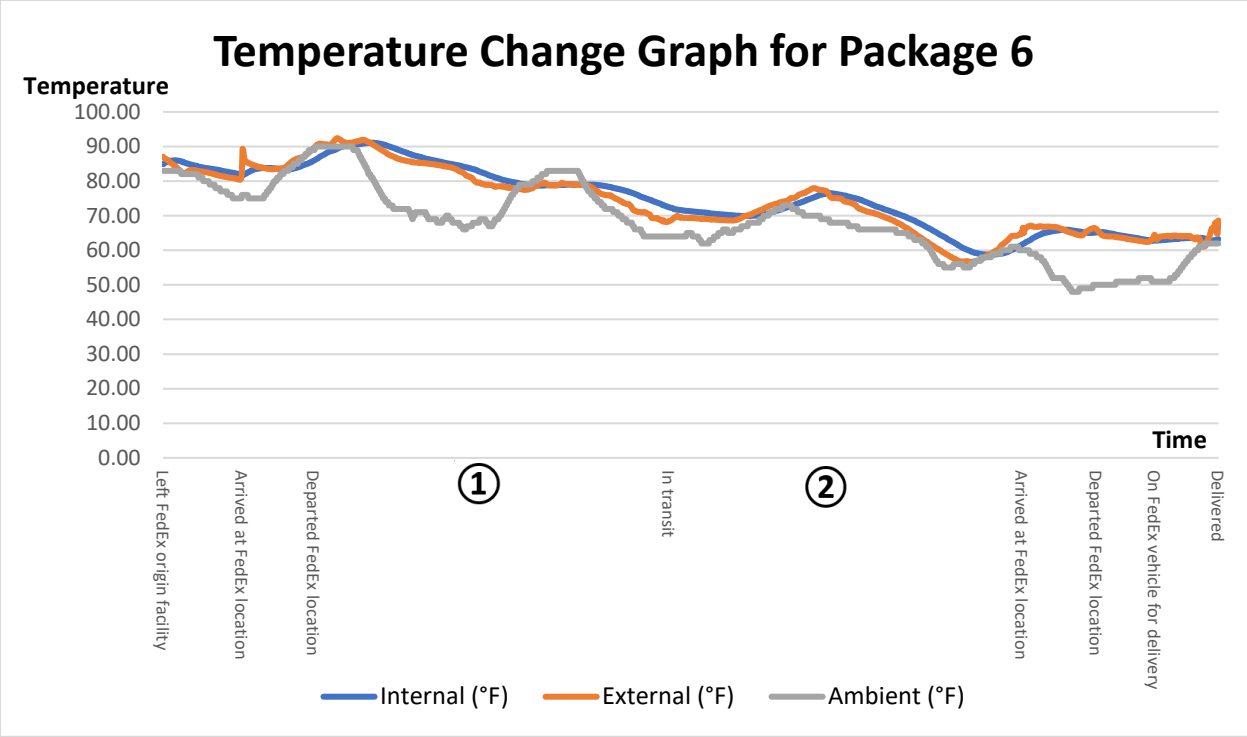

Figure 18. Package 6 Temperature Change Graph

The package was shipped out from the Orlando facility on October 8th at 12:19. When the package was shipped out, the internal temperature was 85.9°F and the external temperature was 89.6°F. The external temperature increased to 91.8°F at 17:13, then started to decrease. The internal temperature increased to 91.1°F at 18:05, and reached the equilibrium at 18:09 when the external temperature decreased to 91.1°F. The equilibrium point continued for 8 minutes, then the external temperature continued to decrease, while the internal temperature remained the same for the next 24 minutes. Both the internal temperature continued to decrease until October 9th at 10:15, the external temperature reached its first minimum peak at 75.5°F. it remained 75.5°F for 20 minutes, then started to increase. Meanwhile, the internal temperature continued to decrease until the second equilibrium point was met at 78.7°F at 11:33 and last for 8 minutes. After the equilibrium, both the internal temperature and external temperature continued to increase. At 12:53, another equilibrium was met at 78.8°F and last for 56 minutes. At 13:57, the temperature raised to 78.9°F but still remain equilibrium for another 8 minutes. Then the internal temperature remained 78.9°F for the next 40 minutes then started to increase at 14:41, while the external temperature started to increase at 14:05. The external temperature increased to 78.5°F at 14:21, then decreased to 79.1°F. the internal temperature

increased to 79.1°F at 15:05, the equilibrium point started again and last for 88 minutes. After that, the internal temperature remained the same for another 72 minutes then started to decrease, while the external temperature started decreasing right after the equilibrium temperature at 16:29.

Table 26. Package 6 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	91.1	92.4	90
Minimum	72.5	68.2	64
Difference	18.6	24.2	26

Within interval 2, the package arrived Tully on October 10th at 1:35. The internal temperature was 72.5°F and the external temperature was 68.4°F when the package arrived. The internal temperature decreased right after the package arrived to the facility, while the external temperature increased to 70°F at 2:25, then started to decrease, while the internal temperature continued to decrease until 9:29 at 69.9°F, for the first equilibrium point. The equilibrium point started at 9:29 and last until 9:41, then the external temperature increased. The temperature continued to decrease until October 11th at 11:01, another equilibrium point was reached at 58.7°F, last for 8 minutes, then both the internal and external temperature both increased. The package arrived at Syracuse facility at 14:37.

Table 27. Package 6 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	76.6	78	73
Minimum	58.7	56.6	55
Difference	17.9	21.4	18

The seventh package was shipped from Rochester, NY on Thursday, October 8th, 2020. The package was dropped of at FedEx location at 19:20 and left the facility to the Syracuse, NY distribution at 23:41. Package was delivered at 15:15 on Monday, October 12th, 2020.

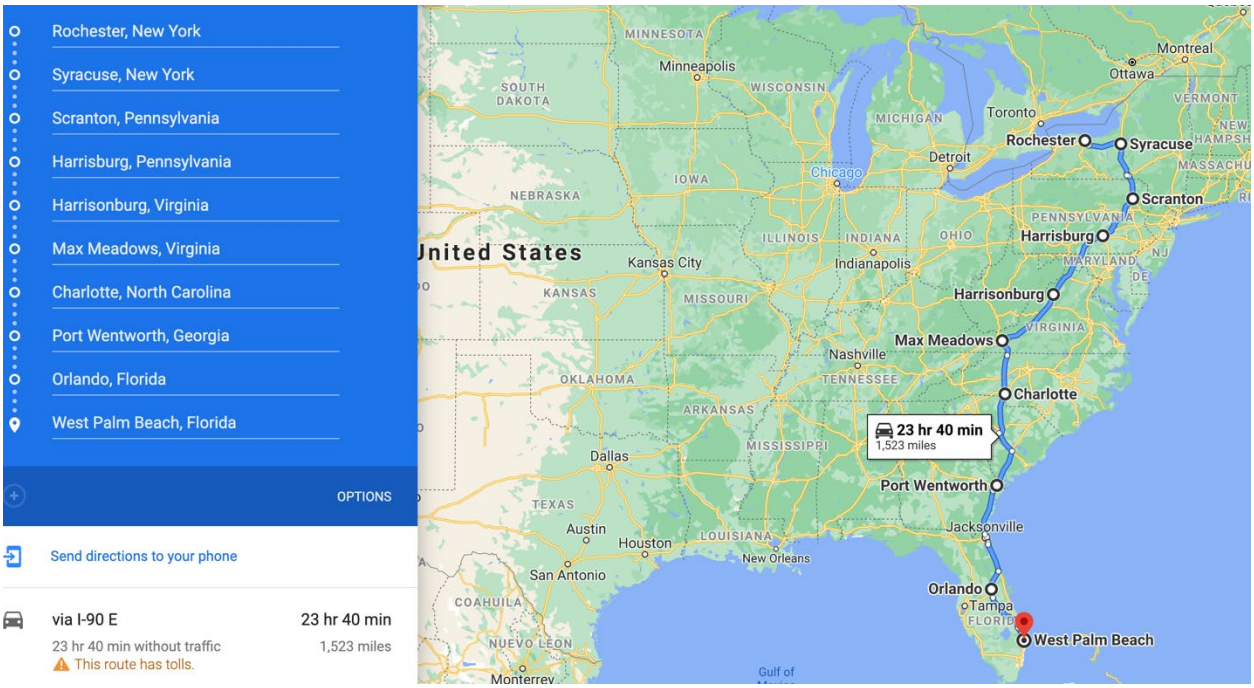

Figure 19. Package 7 Map Route

The graph shown below is the sensor tracked temperature during shipment.

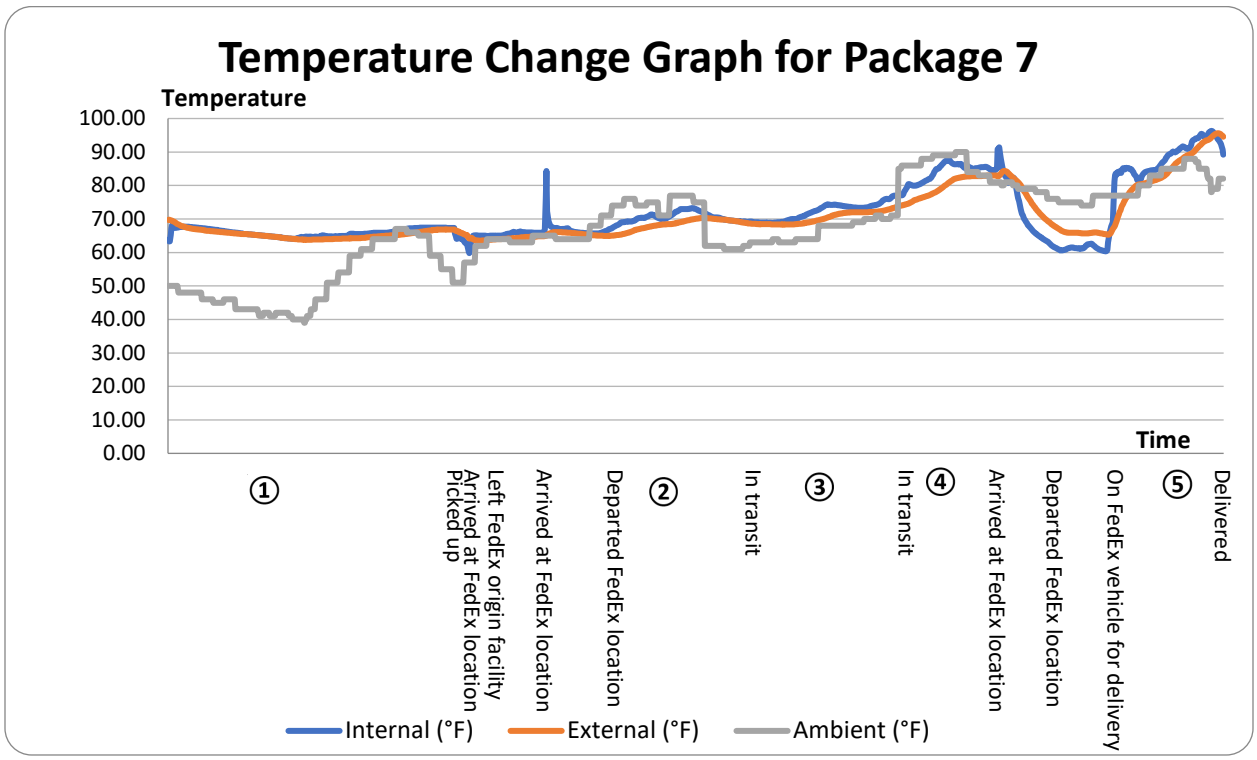

Figure 20. Package 7 Temperature Change Graph

Within interval 1, the package was kept in the FedEx location from October 8th from 19:00 to October 9th 20:08. The package was stored in a constant temperature environment, the equilibrium points appeared frequently in this interval.

Table 28. Package 7 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	68.2	69.8	67
Minimum	63.3	63.8	39
Difference	4.9	6	28

Within interval 2, the package was shipped out from the Syracuse facility on October 10th at 10:08. The internal temperature was 68°F and the external temperature was 65.1°F when the package was shipped out. Both temperatures increased after the package was shipped out. At 16:44, the internal temperature reached its maximum at 73.2°F and lasted for 12 minutes. After that, the temperature decreased. The external temperature reached its maximum temperature at 70.3°F at 17:32 and last for 32 minutes. The first equilibrium point was met at 19:36 at 69.8°F, last for 4 minutes, then decreased to 69.7°F, 69.6°F, 69.5°F, 69.4°F and 69.3°F for the next 64 minutes. After that, the temperature decreased to 69°F internally and 68.6°F externally when the package arrived the transit in Max Meadows.

Table 29. Package 7 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	73.2	70.3	77
Minimum	68	65.1	61
Difference	5.2	5.2	16

Within interval 3, the overall temperature increase matched the estimated ambient temperature. The internal temperature increased faster than the external temperature. From October 10th at 22:20 to October 11th at 11:36, internal temperature from 69°F increased to 79.5°F, external temperature increased from 68.6°F to 74.5°F. There was no equilibrium point within this interval.

Table 30. Package 7 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature

Maximum	79.5	74.5	86
Minimum	68.8	68.3	63
Difference	10.7	6.2	23

Within interval 4, the package arrived the transit in Port Wentworth at 11:35. The internal temperature when the package arrived was 79.5°F and the external temperature was 74.5°F. the internal temperature raised up to 84.4°F 8 minutes after arrival, then started to decrease to 79.9°F at 12:12. After that, the temperature increased up to 87.8°F at 15:20, which was the maximum temperature the internal temperature reached within this interval. after that, the temperature decreased to 85°F then raised up. On the other hand, the external temperature experienced a flatter slop shown on the graph. The external temperature started to increase after the package's arrival. There was no decrease of the temperature throughout the interval. When the package arrived the Orlando FedEx location, the internal temperature was 90.8°F and the external temperature was 82.8°F. What is notable is that at 19:28 before the package scanned through, the internal temperature was 85°F, when the package was scanned at 19:31, the internal temperature increased 5.8°F but the external temperature decreased from 83°F to 82.8°F.

Table 31. Package 7 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	90.8	83	90
Minimum	79.5	74.5	81
Difference	11.3	8.5	9

Within interval 5, the package left the West Palm Beach facility on October 12th at 5:51. The internal temperature was 83.6°F and the external temperature was 68.7°F when the package left the facility. The external temperature reached its maximum temperature at 95.6°F at 14:44, while the internal temperature reached its maximum at 96.3°F at 14:12. The package was delivered at 15:15, when the internal temperature decreased to 89.2°F and the external temperature was 94.6°F.

Table 32. Package 7 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature

Maximum	96.3	95.6	88
Minimum	81.4	68.7	77
Difference	14.9	26.9	11

The eighth package was shipped on October 12th, 2020 from West Palm Beach, FL. The package was dropped off at the FedEx facility at 16:55, and left the West Palm Beach, FL facility at 22:19. The package was transported to Syracuse, NY distribution center, then sent to Rochester, NY for delivery.

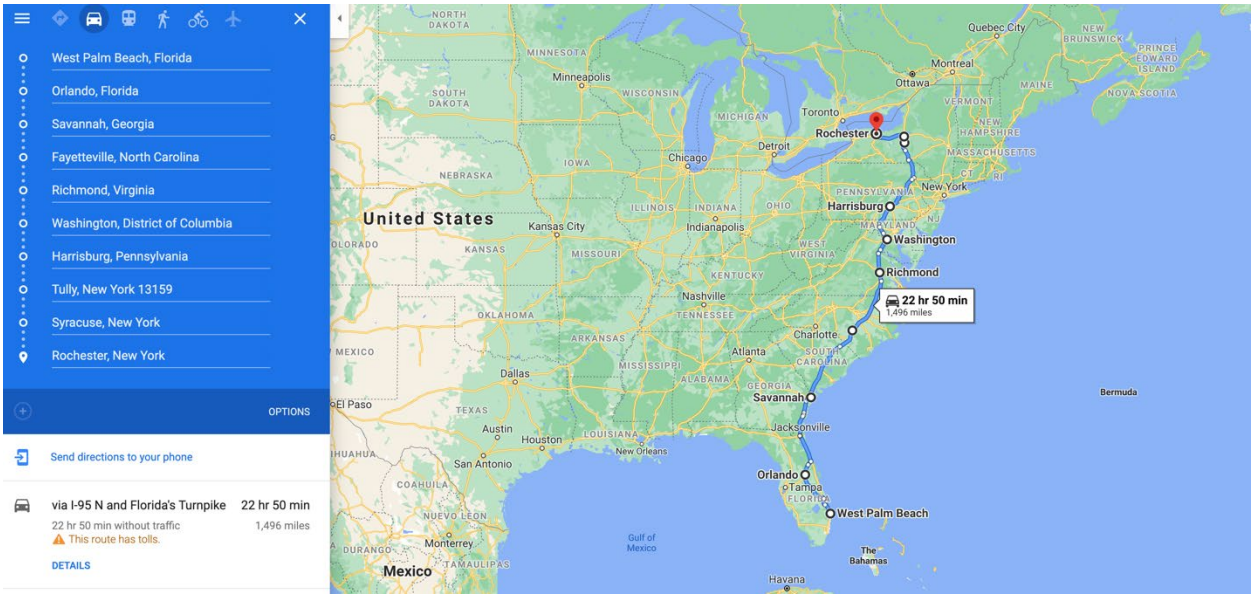

Figure 21. Package 8 Map Route

The graph shown below is the sensor tracked temperature during shipment.

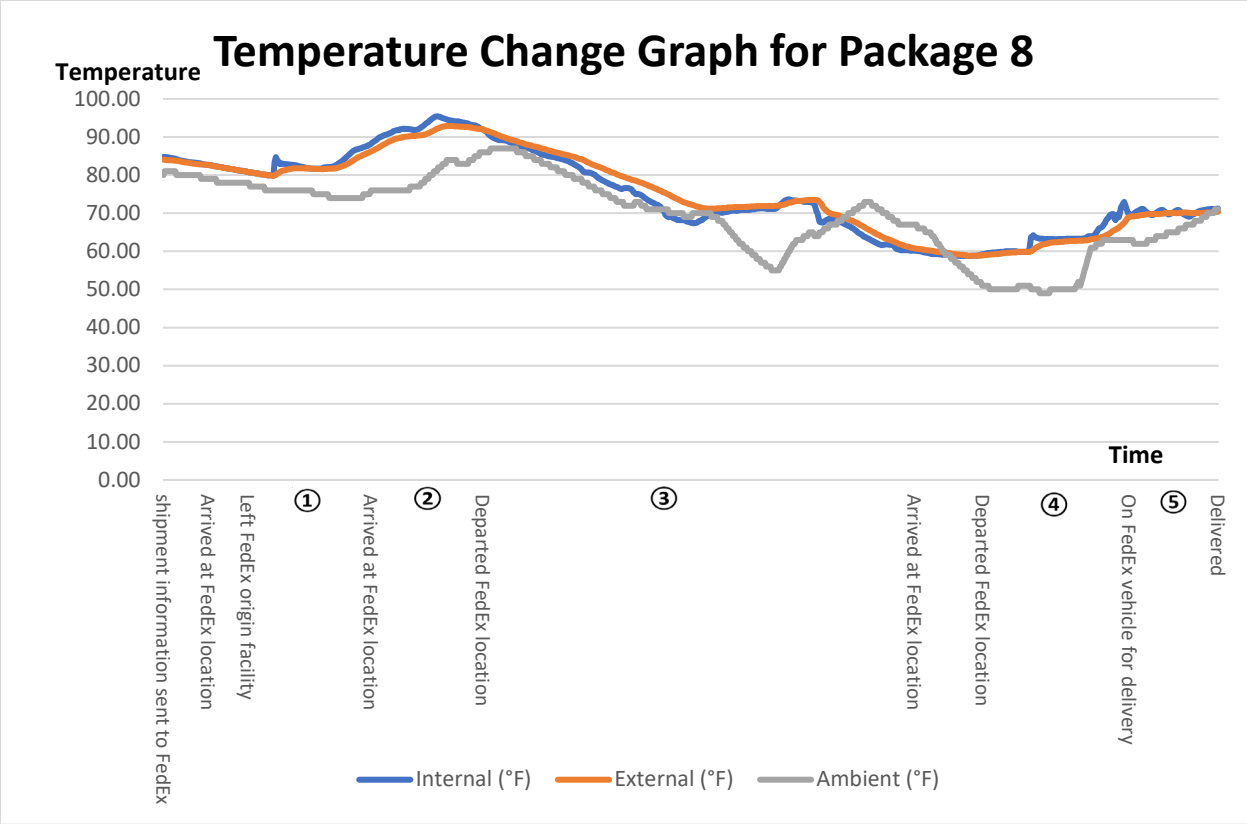

Figure 22. Package 8 Temperature Change Graph

Within interval 1, the package left the West Palm Beach FedEx facility at 22:19 with the both the internal temperature and the internal temperature of 80.9°F. The equilibrium lasted 88 minutes, and the temperature decreased over time from 80.9°F, to 80.7°F, 80.6°F, 80.4°F, 80.3°F, 80.2°F, 80.1°F and 79.9°F. At 23:58, the internal temperature piked up to 83.4°F, then to 84.1°F, then started to decrease, while the external temperature fluctuated between 81°F to 81.8°F. On October 13th at 1:58, the internal temperature and external temperature raised to 81.1 and started equilibrium, lasted for 8 minutes, then decreased down to 81.7°F and lasted for 12 minutes. After that, the internal temperature increased to 88.2°F and the external temperature increased to 86.2°F when the package arrived at the FedEx location at 5:58.

Table 33. Package 8 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	88.2	86.2	78
Minimum	79.9	79.8	74
Difference	8.3	6.4	4

Within interval 2, the package was kept at the FedEx location in Orlando. There was only one equilibrium within this interval, the internal temperature increased to 92.2°F at 8:02, then decreased down to 91.8°F at 8:42. After that, the temperature increased to 95.4°F at 10:02, lasted for 8 minutes, then decreased to 92.1°F at 12:50. The external temperature on the other hand, increased from 86.2°F to 92.9°F at 10:38, last for 28 minutes, then started to decrease. Both internal and external temperature encountered the equilibrium point at 12:50 at 92.1°F, last for 8 minutes. At 12:58, the package left the facility and headed to Syracuse.

Table 34. Package 8 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	95.4	92.9	86
Minimum	88.2	86.2	76
Difference	7.2	6.7	10

Within interval 3, the package left the facility with the internal temperature and external temperature equilibrium. The temperature started tat 92°F decreased to 91.8°F 4 minutes after. The equilibrium stopped at 13:06, then both the internal and external temperature decreased. The internal temperature decreased faster than the external temperature. The internal temperature reached to its minimum at 67.3°F on October 14th at 2:06, while the external temperature was 72.1°F. The internal temperature then started to increase while the external temperature continued to decrease. The external temperature reached to its minimum temperature at 71.2 at 2:58, lasted for 32 minutes, then started to increase. Another equilibrium point was met at 8:30 at 73.3°F. This only last 4 minutes, then the external temperature dropped to 73.2°F while the internal temperature remained at 73.2°F. Four minutes after, the internal temperature decreased to 73.2°F and the equilibrium point was met and last for 12 minutes. After that, the internal temperature decreased but the external temperature raised up to 73.5°F and last for 32 minutes, then decreased. The package arrived the Syracuse facility at 15:54 with the internal temperature of 60.2°F and the external temperature of 60.8°F.

Table 35. Package 8 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	92	92	87
Minimum	60.1	60.8	55

Difference	31.9	31.2	32

Within interval 4, the package was shipped out from the Syracuse facility and send to the West Henrietta facility at 20:11. When the package left the facility, the internal temperature was 59.3°F and the external temperature was 59°F. The temperature increased after the package left the facility. The internal temperatreu increased to 60°F at 21:34 and remain the same for the next 36 minutes, then decreased to 59.9°F and lasted for 40 minutes. The external temperature on the other hand, increased to 59.9°F and reached the equilibrium point at 22:18, last for 40 minutes. After the equilibrium, the internal temperature increased to 69.6°F and the external temperature increased to 69°F when the package was on the delivery truck.

Table 36. Package 8 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	73	69	63
Minimum	59.3	59	49
Difference	13.7	10	14

Within interval 5, the package was out for delivery on October 15th at 5:18. The internal temperature fluctuated between 69.1°F and 71.2°F. The external temperature increased from 69°F to 70.4°F. There were several equilibrium points met but there is no trend to find because of the fluctuation of the internal temperature. the first equilibrium happened at 6:34 with 69.8°F, lasted 4 minutes, then the internal temperature decreased to 69.5°F, and raised back up to 69.8°F at 6:50, started the second equilibrium poin tat 69.8°F and last for 4 minutes. At 7:34 the third equilibrium point was met at 70.1°F and lasted for 4 minutes. At 7:54, the fourth equilibrium point was met at 70°F and last for 8 minutes. At 8:34, the fifth equilibrium point was met at 70.1°F, and the last equilibrium point was met at 9:22 at 70°F and lasted 8 minutes.

Table 37. Package 8 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	71.2	70.4	71

Minimum	69.1	69	62
Difference	2.1	1.4	9

The ninth package was shipped form Rochester, NY to West Palm Beach, FL on October 15th, 2020. The package was dropped off at 19:42 on October 15th, 2020 and left the Rochester, NY facility on October 16th at 21:03, 2020 to the Syracuse, NY distribution center. The package was delivered on October 19th, 2020 at 16:03 at West Palm Beach, FL.

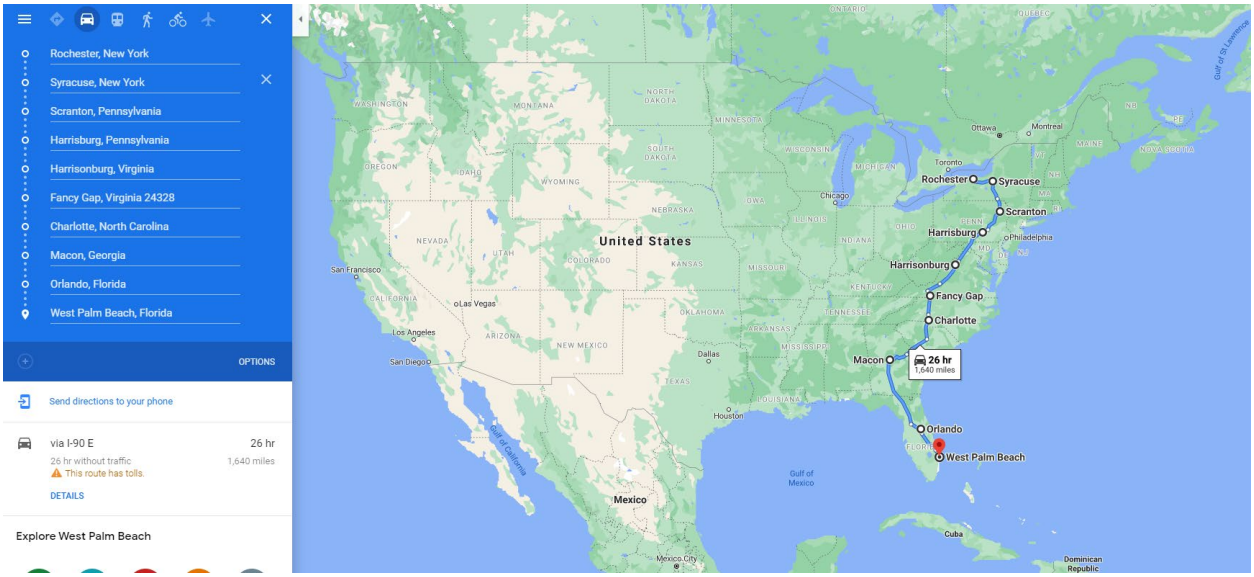

Figure 23. Package 9 Map Route

The graph shown below are the sensor tracked temperature during shipment.

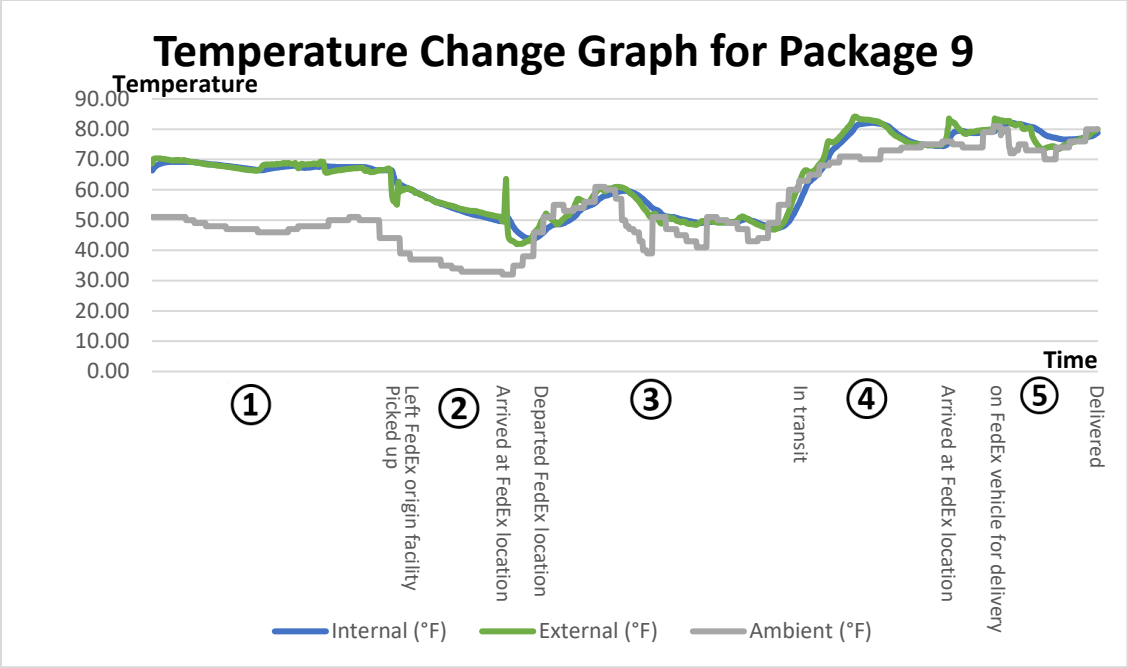

Figure 24. Package 9 Temperature Change Graph

Within interval 1, the package was sent to the FedEx location at 19:42, and picked up at 19:11 the next day. During this time, the package was kept indoor at the FedEx location, with the ambient temperature kept consistent. The internal temperature started at 66.3°F, increased to 69.2°F at 21:12 and remain the same for 144 minutes, then started to decrease. The external temperature started at 68.7°F, increased to 70.4°F and lasted 32 minutes, and started to decrease. The first equilibrium point was met at 23:24 at 69.2°F, last 12 minutes, then both decreased to 69.1°F and lasted 8 minutes. After that, both internal and external temperature decreased to 69°F, 68.9°F, 68.8°F, 68.7°F, 68.4°F over time. The equilibrium ended on October 16th at 1:28 with internal temperature of 68.4°F and external temperature of 68.2°F. The internal temperature decreased to 66.5°F at 6 am, lasted 28 minutes then increased. The external temperature decreased to 66.2°F at 5:44 and lasted 8 minutes before increase. The next equilibrium point was met at 67.9°F at 9:44 but lasted only 4 minutes. The internal temperature fluctuated between 66.4°F to 67.5°F, and the external temperature fluctuated between 66.2°F to 67.3°F, but rejoined the equilibrium point at 66.4°F at 17:40 and lasted 20 minutes, then both increased to 66.5°F and lasted 12 minutes before the package was picked up.

Table 38. Package 9 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	69.2	70.4	51
Minimum	64.7	56.2	44
Difference	4.5	14.2	7

Within interval 2, the package left the West Henrietta facility at 21:03 with both the internal temperature and external temperature of 59.8°F. the equilibrium lasted 4 minutes, then both temperatures decreased with different rate and rejoined the equilibrium temperature at 58.9°F. The equilibrium status remained with both internal and external temperature decreased to 58.8°F, 58.5°F, 58.4°F, 58.2°F, 58.1°F, 57.9°F, 57.7°F, 57.4°F, 57.3°F, 57°F, 56.9°F, 56.3°F, 55.9°F, 55.8°F and 55.7°F in the next 132 minutes. The temperature then decreased with different rate until October 17th at 5:47, both internal and external temperature decreased to 49.6°F and remained equilibrium when the package arrived at the Syracuse facility.

Table 39. Package 9 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	59.8	59.8	37
Minimum	49.5	49.5	32
Difference	10.3	10.3	5

Within interval 3, the package departed from Syracuse FedEx location on October 17th at 9:44 with the internal temperature of 45.5°F and external temperature of 50°F. The first equilibrium temperature was met at 11:08 at 48.6°F, lasted for 4 minutes. After that, the temperature continued to increase. The internal temperature raised to59.7°F at 17:44, lasted 12 minutes then decreased. The external temperature increased to 61°F at 16:56, lasted 12 minutes then decreased. The second equilibrium was met at 18:08 at 59.6°F and last for 4 minutes. After that, the internal remained the same for another 4 minutes at 59.6°F but the external temperature decreased to 59.4°F. On October 18th at 1:08, the third equilibrium was met at 49°F and lasted for 4 minutes. After the equilibrium, both internal and external temperature increased and rejoined equilibrium at 49.3°F at 1:52 and lasted 4 minutes. At 2:20, when the internal temperature raised to 49.5°F and the external temperature decreased to 49.5°F, the equilibrium started again from 49.5°F, decreased to

49.4°F, then to 49.3°F. At 2:52, the temperature remained at 49.2°F for both internal and external and lasted for 64 minutes. After that, the temperature both increased to 49.3°F and lasted 36 minutes before both temperatures increased. At 5:48, both temperatures increased to 50.4°F and lasted 4 minutes, then decreased to 50.3°F and lasted 4 minutes. 4 minutes later at 6:00, the temperature again met at 50.1°F at equilibrium. At 8:04, both temperatures decreased to 47.3°F and lasted 12 minutes, which was the last equilibrium within this interval before the package arrived the Forest Park transit.

Table 40. Package 9 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	59.7	64	63
Minimum	45.5	46.8	39
Difference	14.2	17.2	24

The package arrived the Forest Park transit at 11:04. When the package arrived, the intern temperature was 57°F and the external temperature was 64°F. The internal temperature increased to 82.1°F at 5:48, which was the maximum temperature. The external temperature increased to 84.2°F and lasted for 4 minutes, which was the maximum temperature. Both internal and external temperature then decreased to 81.8°F at 19:00 at equilibrium and lasted 4 minutes. After that, the temperature continued to decrease to 75°F at 10:32. The equilibrium at 75°F lasted 20 minutes, then both decreased to 74.9°F and lasted 8 minutes, then both decreased to 74.8°F for 12 minutes, then decreased to 74,7°F and lasted 32 minutes. Both temperatures continued to increase after the equilibrium stopped at 23:56.

Table 41. Package 9 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	82.1	84.2	76
Minimum	57	64	63
Difference	25.1	20.2	13

Within interval 5, package was placed on the delivery truck on October 19th at 6:20. The internal temperature was 80.6°F and the external temperature was 83.2°F when the package left the facility. The internal temperature first increased to 82.1°F at 7:28 and lasted 16 minutes. The external temperature

decreased to 82.1°F at 7:32 and met the first equilibrium for 4 minutes. At 8:12, the second equilibrium was met at 81.7°F and lasted 4 minutes. The internal temperature then decreased to 76.6°F, external temperature decreased to 73.3°F then increased and rejoined equilibrium at 97.9°F at 14:28 and lasted 4 minutes. Both temperature then raised to 77°F and 77.2°F in the next 12 minutes remaining equilibrium.

Table 42. Package 9 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	82.1	83.2	81
Minimum	76.6	73.3	70
Difference	5.5	9.9	11

The tenth package and the eleventh package were shipped together. Both packages share the same route but with separate tracking number. Both of the packages were dropped off at the FedEx Rochester, NY facility on October 26th, 2020 at 19:46. Packages were picked up and shipped to the Syracuse, NY facility at 0:28 on October, 28th, 2020. The packages were kept at the warehouse for 1 day.

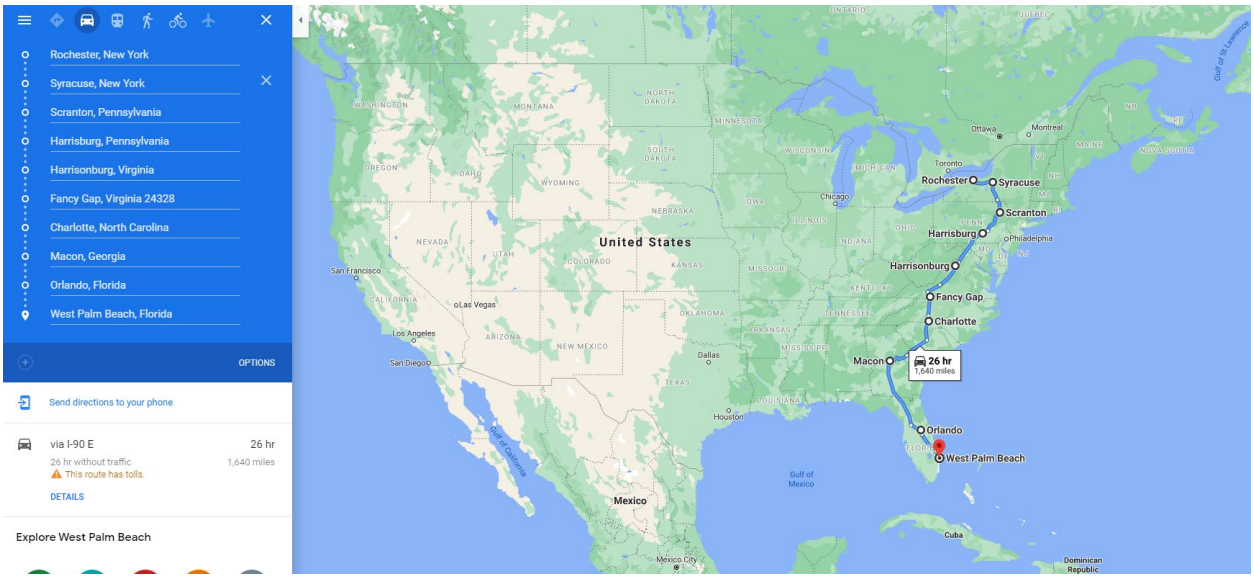

Figure 25. Package 10/11 Map Route

The graph shown below are the sensor tracked temperature during shipment.

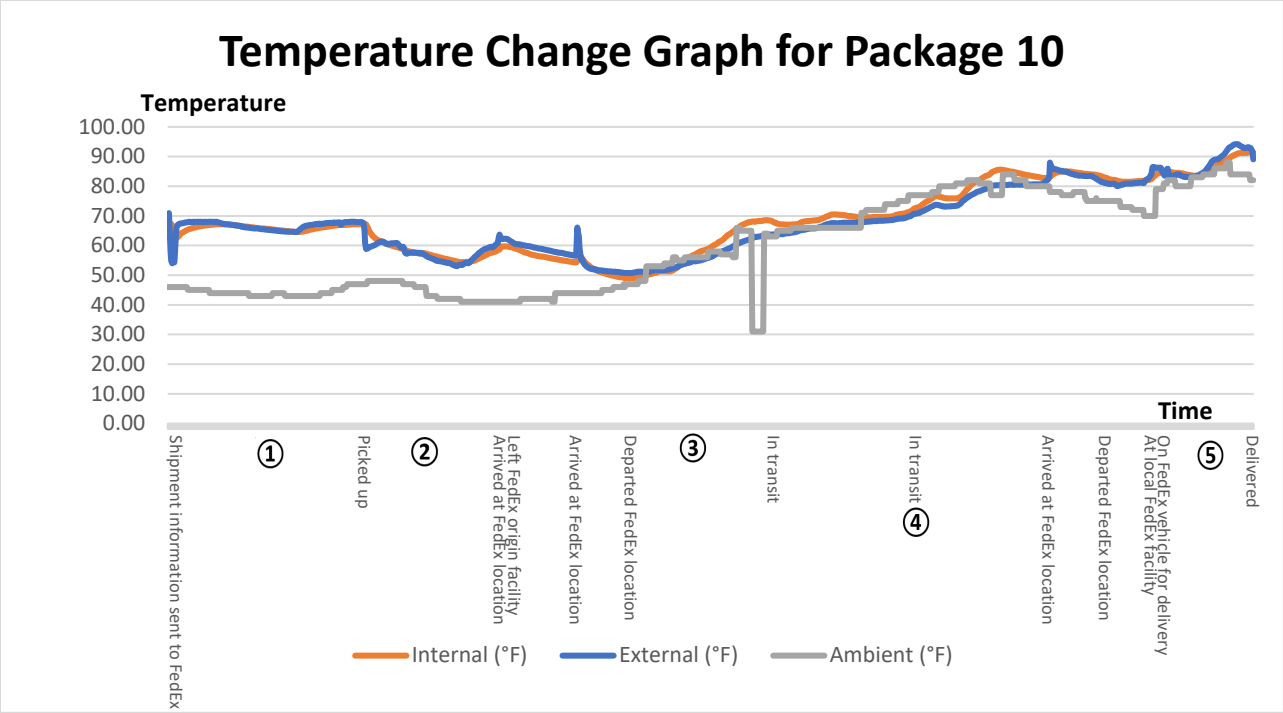

Figure 26. Package 10 Temperature Change Graph

Within interval 1, the package was kept at the FedEx drop off location. The indoor temperature was kept approximately 67°F, therefore the recorded temperature fluctuated between 64°F and 68°F. When the package arrived the FedEx location, the internal temperature was 62.6°F and the external temperature was 66.2°F. The first equilibrium was reached at 23:52 at 67.1°F, lasted 16 minutes, then both decreased to 67°F, 66.9°F, 66.8°F, 77.6°F, 66.6°F and 66.4°F in the next 76 minutes. The second equilibrium was met at October 27th at 5:16 at 64.7°F and lasted 24 minutes; then the external temperature decreased to 64.6°F, the internal temperature decreased to 64.6°F 4 minutes later, and started equilibrium at 64.6°F for 8 minutes. The last equilibrium was met at 9:40 at 66.9°F, lasted only 4 minutes, the external temperature increased but the internal temperature remained the same for the next 24 minutes then increase.

Table 43. Package 10 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	67.3	68	47
Minimum	62.6	60.8	43
Difference	4.7	7.2	4

The package was picked up at 11:44 from the FedEx drop off location to the distribution center. When the package was picked up, the internal temperature was 67.3°F and the external temperature was 60.8°F. Both internal and external temperature decreased to 61.3°F at 13:08 to reach the first equilibrium. The equilibrium lasted 4 minutes, then the internal temperature decreased to 61.1°F, 60.9°F and 60.8°F; external temperature remained at 61.3°F, then decreased to 61.1°F and 60.9°F, then rejoined equilibrium at 60.8°F and lasted 12 minutes. After that, the temperature continued to decrease, at 15:52, another equilibrium was met at 57.6°F, lasted 4 minutes, then the internal temperature increased to 57.7°F for 8 minutes, decreased to 57.6°F and rejoined the equilibrium for another 8 minutes. Twenty minutes later, another equilibrium was met at 57.4°F at 16:31 but only lasted 4 minutes before the temperature continued to decrease. The last equilibrium was met at 20:35 at 54.5°F for 8 minutes, then the temperature increased until the package arrived at the West Henrietta facility.

Table 44. Package 10 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	67.3	63.7	48
Minimum	54.4	53	41
Difference	12.9	10.7	7

Within interval 3, the package departed from the Syracuse distribution with the internal temperature of 49°F and external temperature of 50.7°F. There was only 2 equilibrium points were reach within this interval. The first one was met at October 28th at 14:12 at 52.7°F. the equilibrium lasted only 4 minutes, then the external temperature increased to 52.8°F for 4 minutes, then increased to 53°F, but 4 minutes later the internal temperature increased to 53°F and rejoined equilibrium for 4 minutes. After that the temperature continued to increase.

Table 45. Package 10 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	68.5	63.7	66
Minimum	49	50.7	31
Difference	19.5	13	35

Within interval 4, the package left Fancy Gap facility at 22:27 with internal temperature of 67.7°F and external temperature of 63.7°F. Both internal temperature and external temperature increased over time. There was no equilibrium within this interval.

Table 46. Package 10 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	85.6	83.1	84
Minimum	67	63.7	63
Difference	18.6	19.4	21

Within interval 5, the package left the facility for delivery at October 30th at 7:37. Four minutes later, the first and only equilibrium was met at 84.7°F and last for 4 minutes. After that the temperature continued to increase until delivered.

Table 47. Package 10 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	91.5	94.2	88
Minimum	83.4	83.1	80
Difference	8.1	11.1	8

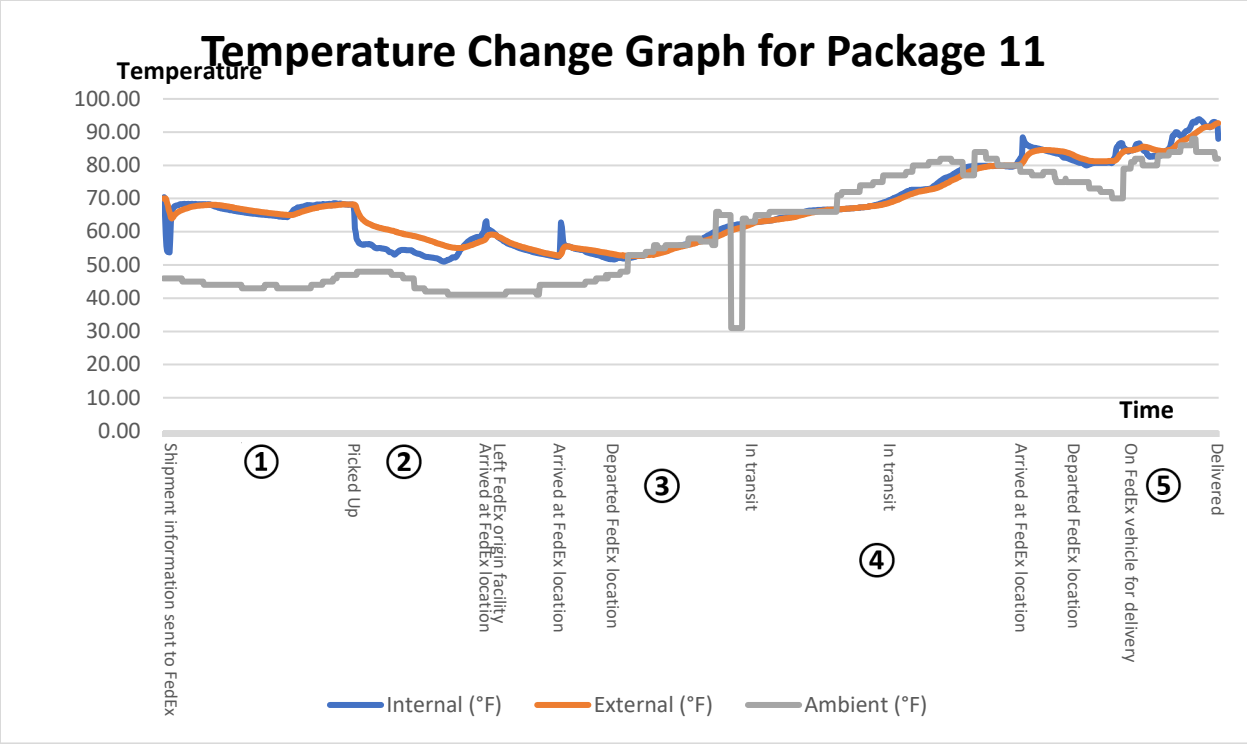

Figure 27. Package 11 Temperature Change Graph

Within interval 1, the package was kept at the FedEx drop off location. The indoor temperature was kept approximately 67°F, therefore the temperature fluctuated between 64°F to 69°F. The internal temperature was 65.5°F and the external temperature was 64°F when the package was dropped off. The temperature increased until 22:52 to reach the first equilibrium at 68.1°F and remained 20 minutes. After that, the temperature started to decrease by different rates. The internal temperature decreased to 64.4°F on October 27th at 5:48, lasted 4 minutes then increased. The external temperature decreased to 65°F at 5:48 and lasted 32 minutes. At 6:00 when the internal temperature increased to 65°F, there was 4 minutes of equilibrium, then continued to increase. At 9:40, the third equilibrium was met at 67.9°F and lasted 8 minutes, then the temperature kept increase until 10:40 reached the last equilibrium within this interval at 68.3°F. The equilibrium lasted 68.3°F for 12 minutes, then both decreased to 68.2°F and lasted 12 minutes. After that, the internal temperature decreased to 68.1°F for 8 minutes, while the external temperature remain at 68.2°F, then the internal temperature raised back up to 68.2°F and lasted 16 minutes for equilibrium before temperature continued to decrease.

Table 48. Package 11 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	68.6	68.3	47
Minimum	61	64	43
Difference	7.6	4.3	4

The package was picked up at 11:44 to the West Henrietta facility with internal temperature of 61°F and external temperature of 68.1°F. The temperature decreased after the package was picked up and reached the only equilibrium at 21:04 at 55.1°F for 8 minutes. After the equilibrium, both the internal and external temperature increased.

Table 49. Package 11 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	63.2	68.1	48
Minimum	51	55.1	41
Difference	12.2	13	7

The package was picked up from the Syracuse facility at 10:21 with the internal temperature of 51.6°F and external temperature of 53.3°F. After the package as picked up, the internal temperature increased but the external temperature decreased. At 0:16 on October 28th, the first equilibrium was met at 52.7°F and lasted 20 minutes. After that, both internal and external temperature increased to 52.8°F and lasted 12 minutes, then increased to 52.9°F and lasted 4 minutes. After that, the internal temperature started to increase to 53.1°F while the external temperature remained at 52.9°F for 4 minutes then increased to 53°F. This was the only equilibrium point reached within this interval.

Table 50. Package 11 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	62.9	62.4	66
Minimum	51.6	52.7	31
Difference	11.3	9.7	35

Within interval 4, the package arrived the Fancy Gap facility at 22:27 with the internal temperature of 62.9°F and external temperature of 62.4°F. The first equilibrium was met at 22:48 at 62.9°F for 8 minutes. Both the internal temperature and external temperature increased to 63°F, 63.1°F, 63.2°F, 63.3°F 63.4°F, 63.5°F and 63. °F until October 29th at 0:24. Both the internal and external temperature then increased 66.7°F at 5:00 for the next equilibrium and lasted only 4 minutes. After the four minutes, the internal temperature remained the same, but the external temperature fluctuated to 66.6°F for 12 minutes, then increased back to 66.7°F and rejoined the equilibrium for 32 minutes. Both internal and external temperature then increased to 66.8°F, 66.9°F, 67°F, 67.1°F, 67.2°F, 67.3°F, 67.4°F, 67.5°F 67.7°F until 5:56. After the equilibrium, the internal temperature then increased to 67.9 while the external temperature remained at 67.7°F for another 8 minutes. The temperature continued to increase at different rate, and the final equilibrium within this interval was met at 19:36 at 79.9°F and lasted 48 minutes. After the equilibrium, the internal temperature remained at 79.9°F for another 4 minutes, then decreased to 79.7°F and 79.6°F before increased again, while the external temperature directly increased to 80°F.

Table 51. Package 11 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	81.9	80.2	84
Minimum	62.9	62.4	63
Difference	19	17.8	21

Within interval 5, the package was placed on the delivery truck on October 30th at 7:37. The equilibrium was met at the moment at 84.5°F and lasted 12 minutes. After that, the internal temperature increased to 86.6°F and remained 8 minutes at 8:12, then decreased. The external temperature increased to 85.7°F at 8:32 and lasted 8 minutes, then decreased. The next equilibrium was met at 10:24 at 84.2°F for 12 minutes, then both internal and external temperature increased with different rates until 14:08 at equilibrium at 91.6°F, lasted 16 minutes. After that, at 14:56 the last equilibrium was met at 92.5°F and remained 4 minutes.

Table 52. Package 11 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	93.9	92.7	88

Minimum	82.6	84.2	80
Difference	11.3	8.5	8

The twelfth package was shipped from West Palm Beach, FL to Rochester, NY together on November 3rd, 2020. The packages was dropped off at the West Palm Beach, FL FedEx facility at 16:39 and left the facility at 20:28. The packages was delivered at Rochester, NY on November 6th, 2020 at 12:28.

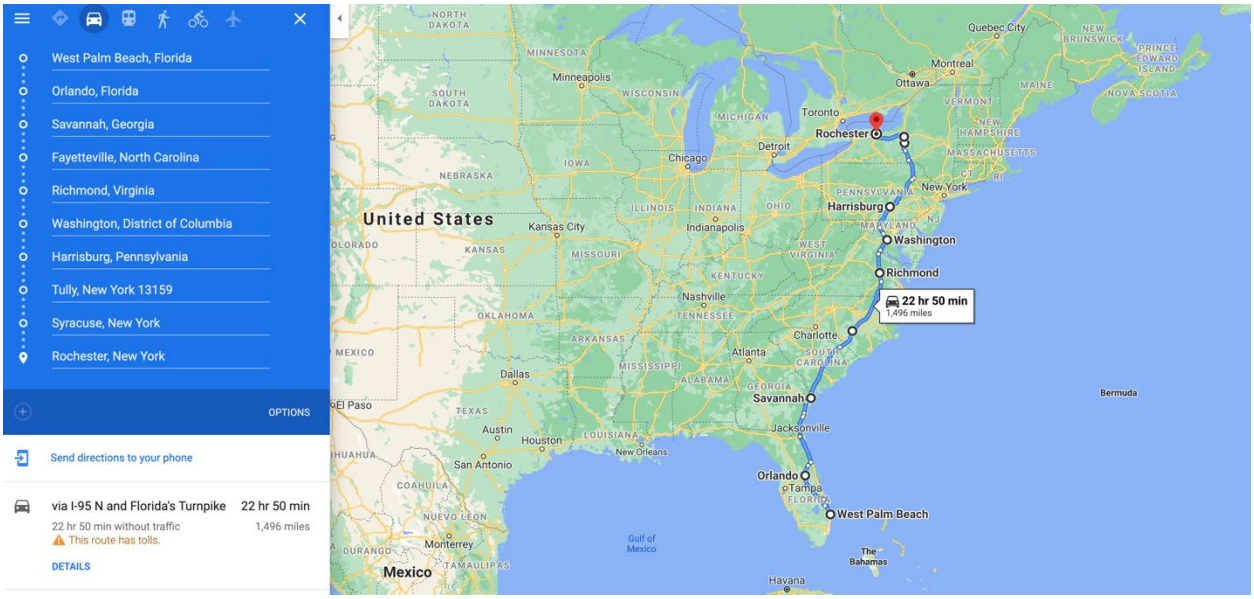

Figure 28. Package 12 Map Route

The graph shown below are the sensor tracked temperature during shipment.

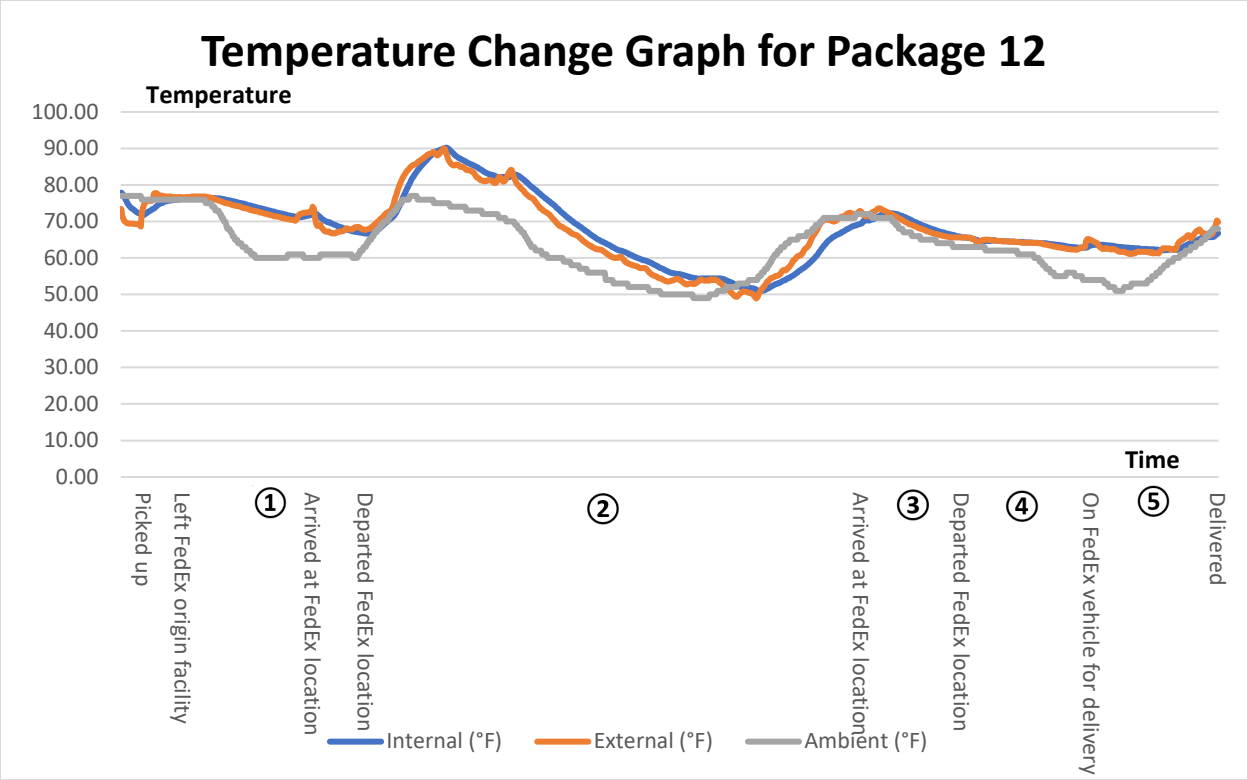

Figure 29. Package 12 Temperature Change Graph

Within interval 1, the package left the West Palm Bach facility on November 3rd at 20:28 with the internal temperature of 76.1°F and external temperature of 76.6°F. As the package left the facility, the internal temperature increased to 76.5°F at 22:07, while the external temperature raised to 76.8°F at 21:07, lasted 44 minutes then decreased to 76.5°F at 22:03. The first equilibrium was met at 22:07 and lasted for 12 minutes. After the equilibrium, the temperature started to decrease until the package arrived the Orlando facility at 4:27 on November 4th.

Table 53. Package 12 Interval 1 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	76.5	76.8	76
Minimum	71.1	70.2	60
Difference	5.4	6.6	16

Within interval 2, the package departed from the Orlando facility and headed to the Syracuse facility at 7:43 with the internal temperature of 66.7°F and external temperature of 67.7°F. The temperature increased after the package was sent out. The first equilibrium was met at 12:31 at 90°F and lasted only 4 minutes.

This was the maximum temperature the external temperature reached. After the equilibrium, the internal temperature continued to increase to 90.2°F and lasted 8 minutes, then started to decrease. At 15:55, the second equilibrium was met at 82.2°F and lasted 8 minutes. After this equilibrium, there was a slight temperature increase, the internal temperature reached 82.8°F at 16:55 and lasted 8 minutes, while the external temperature raised to 84.1°F at 16:39 and lasted 8 minutes. After that, the temperature continued to decrease. At 8:03 on November 5th, the third equilibrium was met at 51°F and lasted only 4 minutes. After that, the temperature started to increase until the package arrived the Syracuse facility.

Table 54. Package 12 Interval 2 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	90.2	90	77
Minimum	51	48.9	49
Difference	39.2	41.1	28

Within interval 3, the package arrived the Syracuse facility at 14:16 with internal temperature of 69.4°Fand external temperature of 72.6°F. The temperature increased to 72.3°F at 15:55 and reached the equilibrium point for 8 minutes. After the equilibrium, the temperature started to decrease until the package was shipped out.

Table 55. Package 12 Interval 3 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	72.3	73.6	72
Minimum	65.6	65.6	63
Difference	6.7	8	9

The package departed from Syracuse facility at 20:27 at equilibrium of 65.6°F. The equilibrium lasted 32 minutes at 65.6°F, then decreased to 65.3°F for 8 minutes. After that, the temperature decreased to 65.2°F for 4 minutes, and 65°F for 4 minutes. The equilibrium then stopped at 21:19, both internal and eternal temperature decreased until 22:19 and reached the second equilibrium at 64.8°F. The equilibrium at 64.8°F lasted 12 minutes, then decreased to 64.7°F for 20 minutes, then decreased to 64.6°F for 20 minutes, and 64.4 for 16 minutes. On November 6th at 0:23, another equilibrium was met at 64.1°F and lasted 16 minutes,

then the temperature dropped to 64°F and lasted 12 minutes. The last equilibrium was met at 3:47 at 62.8°F for 16 minutes, before the package was out for delivery.

Table 56. Package 12 Interval 4 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	65.6	65.6	63
Minimum	62.8	62.2	54
Difference	2.8	3.4	9

Within interval 5, the package was shipped out at 4:25 with the internal temperature of 63.5°F and the external temperature of 64.8°F. The temperature decreased after the package was shipped out, the external reached its minimum at 6:47 at 61.1°F then the temperature increased, while the internal temperature decreased slowly, and the first equilibrium was met at 9:23 at 62.3°F and lasted 8 minutes. Four minutes later, when the internal temperature decreased to 62.2°F, the external temperature dropped to 62.2°F form 62.5°F and reached equilibrium for 4 minutes.

Table 57. Package 12 Interval 5 Temperature Analysis

	Internal Temperature	External Temperature	Ambient Temperature
Maximum	66.8	70.3	68
Minimum	62.1	61.1	51
Difference	4.7	9.2	17

CONCLUSION

The sensor placed in the insulation container showed that the temperature in the insulation box is affected by the distribution environment. From the data above, the internal temperature is more stable, and the difference within each interval is shown less than the external temperature. When the external temperature changes, within 10 minutes the internal temperature would follow the changing trend of the external temperature, regardless of whether the temperature increased or decreased. The equilibrium of the internal and external temperature does not normally happen at the maximum or minimum temperature. When the temperature increase, the external temperature tends to increase faster than the internal temperature, after

the maximum temperature was reach, the temperature started to decrease, the internal temperature would then hit the same temperature and hit the equilibrium. If the equilibrium last for long enough, and the external temperature continues to decrease, the equilibrium would be the maximum temperature of the internal temperature, and the internal temperature would start to decrease after the equilibrium. This could happen only when the temperature change is minor and does not fluctuate frequently. On another hand, if the temperature fluctuates frequently, the equilibrium would not last for long. Due to the fact that the sensors recorded the temperature every 4 minutes, the shortest equilibrium recorded would only be 4 minutes. For example, if the external temperature increases fast then decrease fast, the internal temperature would increase and reach the equilibrium for at least 4 minutes, but after that it would continue to increase, then start to decrease. The ambient was estimated from the route that the package travelled, and the internal temperature/external temperature match the raise and drop trend with the ambient temperature. Therefore, the ambient temperature would affect the distribution environment for the general increase and decrease trend, but the distribution temperature does not fluctuate as significant as the ambient temperature.

During the ground shipment method, the distribution environment was not controlled, the temperature would follow the overall ambient temperature to change. The insulation box worked as the heat blocker, would certainly delay the increase of the internal temperature for approximately 5-10 minutes. Unless the temperature fluctuate too much that the external temperature is unstable, the internal temperature tends to change with a steady rate, the maximum and minimum temperature reached would be minor.

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APPENDIX

APPENDIX 1: FedEx Tracking Information

Appendix 2: Data Collection